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Guidance for Planning the Location of Water Supply Intakes Downstream from Municipal Wastewater Treatment Facilities

Culp/Wesner/Culp, El Dorado Hills, CA

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Clean Water Consultants
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The purpose of this report is to present information and guidelines relevant to the location of surface water supply intakes downstream from municipal wastewater discharges. The report makes no attempt to provide standards or rules to be used in all situation. Decisions on the location of water supply intakes must be made by informed professionals at the local level after careful consideration of all factors and this report is intended to provide information that will be useful to local professional and review officials. The report reviews the data required for evaluating intake location, available stream modeling techniques, capability and costs of water and wastewater treatment processes and the public health implications of upstream wastewater discharges.

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GUIDANCE FOR PLANNING THE LOCATION OF WATER SUPPLY INTAKES DOWNSTREAM FROM MUNICIPAL WASTEWATER TREATMENT FACILITIES

Contract No. 68-01-4473

Project Officer
Patrick Tobin
Office of Water Supply
U. S. Environmental Protection Agency
Washington, D. C. 20460

April, 1978

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This report has been reviewed by Culp/Wesner/Culp, EPA, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

EXECUTIVE SUMMARY

PURPOSE

The purpose of this report is to present information and guidelines relevant to the location of surface water supply intakes downstream from municipal wastewater discharges. The report makes no attempt to provide standards or rules to be used in all situations. Decisions on the location of water supply intakes must be made by informed professionals at the local level after careful consideration of all factors and this report is intended to provide information that will be useful to local professionals and review officials. The report reviews the data required for evaluating intake location, available stream modeling techniques, capability and costs of water and wastewater treatment processes and the public health implications of upstream wastewater discharges.

PROJECTING RAW WATER SUPPLY QUALITY

The many natural and human factors which affect stream water quality cause large variations in the concentrations of trace contaminants as well as constituents commonly found in waters such as chloride, sulfate, calcium, and sodium. Variations can occur within relatively short distances in streams and such variations often occur in an unsystematic and nonpredictable manner. The concentrations of contaminants in streams are affected by reactions such as precipitation, complexation, oxidation-reduction, ion exchange, adsorption and/or absorption, flocculation, and biological uptake and/or release. Stream physical characteristics which affect the fate of contaminants include velocity, depth, turbulence, degree of mixing, temperature, turbidity, changes in cross section and bottom characteristics such as slope, type of material and sorptive capacity. The effects of some of these parameters are so interrelated that their relative importance is difficult to determine.

Despite the complexity of surface water systems, mathematical models have been developed which provide useful insights into the fate of various contaminants. The models generally fall into three categories: (1) steady-state models in which the variables involved are unchanging with time, (2) dynamic-equilibrium models that vary with time but only in a cyclically repetitious manner, and (3) dynamic models in which the inputs and outputs may vary freely with time. Available models are briefly described and their limitations and data requirements are presented. All of the models contain constants that deal with dispersion, sorption, reaeration and diffusion rates. The values of these constants should be obtained through experimental work for the river basin being modeled.

The U.S. Geological Survey operates a water quality network that obtains data from 345 stream monitoring stations in the United States. The Environmental Protection Agency (EPA) has recently completed a survey of the quality of raw water supplies, including 35 surface supplies, to determine the presence of trihalomethanes and the effects of water treatment processes. The study found that 35 surface supplies had a median chloroform concentration of less than 0.2 μg/l and that chlorination of these supplies resulted in formation of trihalomethanes. Based on a review of the data collected in the EPA survey and other available surface water data, the following background stream concentrations of organics were used in analyzing the effects of wastewater discharges on downstream water supplies: biochemical oxygen demand (BOD) = 5 milligrams per liter (mg/l); chemical oxygen demand (COD) = 30 mg/l; total organic carbon (TOC) = 10 mg/l.

With the exception of turbidity and coliform bacteria, most raw surface supplies do not exceed the Federal Primary and Secondary Drinking Water Regulations. Although secondary municipal effluents also do not normally exceed Drinking Water Regulations limits for inorganic chemicals, they do contain turbidity, organic compounds, and pathogens of concern in downstream water supplies. Trace organics are the most important concern because of their largely unknown long term health effects in drinking water.

The public policy adopted by EPA's Office of Drinking Water has been that the Drinking Water Regulations are applicable to tap water whose water supply source is relatively free from pollution. This public policy is further interpreted by the public health agencies that these standards are not comprehensive for determining the adequacy for the reuse of municipal wastewaters for potable purposes. This policy is based upon public health prudence. Until scientific evidence can assure that there is no present or potential adverse effects from the use of wastewaters for potable purposes, this public policy will probably continue.

CAPABILITY OF TREATMENT PROCESSES FOR CONTAMINANT REMOVAL

Several levels of wastewater and water treatment may be used to achieve varying removals of the contaminants specified in the Drinking Water Regulations. These contaminants are divided into the following categories: microbiological, turbidity, organic chemicals, inorganic chemicals and radioactive materials.

Microbiological - Conventional wastewater treatment processes (primary and biological secondary treatment plus chlorination) may achieve at least 90 percent reductions of virus and bacteria but cannot provide a completely disinfected effluent. Conventional water treatment and advanced wastewater treatment (AWT) processes such as chemical clarification, and filtration coupled with chlorination or ozonation can provide complete removal of viruses and coliform bacteria.

Turbidity - Modern water treatment methods can routinely produce water to meet the drinking water requirements for turibidity. Typical secondary effluent turbidities of 10-30 turbidity units (TU) can be reduced to 0.1-1.0 TU by AWT processes.

Organic Chemicals - Some trace organics, many of which are by-products of the chlorination process, are potential carcinogens. In general, the formation of these compounds can be minimized by chlorinating at the point in the water treatment process with the highest quality water. Other control methods include: (1) use of disinfectants which do not generate trihalomethanes, (2) treatment to reduce precursor concentration prior to chlorination, and (3) treatment to reduce the trihalomethane concentrations after formation.

Typical secondary effluent COD levels of 60-100 mg/l have been reduced to as low as 3 mg/l by AWT processes, including granular activated carbon adsorption. However, COD values of 10-12 mg/l appear to represent a more practical level achievable in full-scale, continuous treatment of municipal wastewaters. Reverse osmosis treatment of effluent from the carbon adsorption process can reduce the COD level to 1 mg/l or less in both water and wastewater treatment systems.

Inorganic Chemicals - Chemical clarification is the most generally applicable method for removal of inorganic chemicals in water and wastewater treatment systems. Although toxic inorganic chemicals are not normally present in raw surface waters or municipal secondary effluent, in concentrations that exceed the Drinking Water Regulations, the efficiencies of specific water and wastewater unit processes for removal of arsenic, barium, cadmium, chromium, fluoride, lead, mercury, nitrate, selenium, silver, copper, iron, manganese, zinc, hardness and total dissolved solids are examined in the report.

Radioactive Material - Radioactive materials are not normally present in surface water supplies or municipal wastewaters at levels that exceed the Drinking Water Regulations. Treatment of water containing radioactive materials may present special problems that are not considered in this report.

FACTORS IN LOCATING WATER INTAKES

Exclusive of wastewater discharges, there are many factors to be considered in locating an intake, such as, quality difference between potential sources, adequacy of quantity, accessability, siltation potential, navigation needs, flood levels and foundation conditions. Rural and urban runoff and accidental spills can contribute to public health problems even in the absence of upstream wastewater discharges and intake locations should be selected to minimize these potential problems.

There is a lack of raw water quality standards applicable to both polluted water supply sources and to relatively unpolluted sources on which drinking water regulations are now based. This lack causes many uncertainties for water supplies downstream of wastewater discharges when such discharges constitute a significant portion of the supply. Although there are many water plants which now produce biologically safe drinking water from streams and rivers containing substantial amounts of wastewater, there is uncertainty about the long term effects of the organic materials which may survive both natural purification processes in the stream and water and wastewater treatment processes. Current standards for inorganic compounds appear adequate. Although there are questions about the adequacy of the coliform bacteria standards, there is a lack of water-borne viral diseases in communities with water supplies meeting coliform standards. Standards for organics are the greatest unanswered question.

Of great practical importance is the effect that wastewater discharges have on the distance that should be maintained between an intake and the wastewater discharge. Clearly, some significant separation should be provided to take advantage of natural purification processes and to allow time for adequate monitoring and detection of upstream wastewater plant malfunctions. It appears that at least 24 hours of combined time in travel and storage should be provided to allow for reaction time to emergencies. Greater separation to allow more treatment through natural processes may or may not be more economical than equal removal by improved treatment. Many toxic materials are not effectively removed by natural processes and added separation primarily provides increased time for detection. Increased separation provides more time for die-off of pathogens but complete removal of pathogens can be provided by treatment processes. Time of stream travel probably has little effect on any health hazards from synthetic organics.

Several studies document the fact that wastewater treatment plants often do not operate at their design efficiency. Such inefficiencies or periodic failures may be particularly significant to downstream water supplies. Conventional plant designs can be modified to greatly increase reliability, although at increased cost.

ALTERNATIVES IN WATER INTAKE LOCATIONS

In order to compare the effects of several variables that must be considered when evaluating potential water intake locations, a wastewater discharge-water intake and supply model system was established. The system variables include: (1) level of wastewater treatment, (2) separation time between the point of wastewater discharge and the water intake, (3) quantity of wastewater as a percentage of total stream flow, (4) level of wastewater treatment, and (5) relative sizes of the wastewater and water treatment plants. In addition to secondary wastewater treatment, AWT (inluding lime clarification, filtration, and carbon adsorption) was considered. Levels of water treatment considered were "conventional,"upgraded" (Chemical clarification, mixed media filtration, and granular carbon adsorption), and "upgraded plus reverse osmosis". The following average organic concentrations and percentage removals are used in the cases evaluated:

	Concentration, mg/l			Percentage Removal		
	BOD	COD	TOC	BOD	COD	TOC
Stream Flow	5	30	10	--	--	--
Effluents						
Secondary	30	100	40	--	--	--
Advanced Wastewater Treatment	2	20	8	93	80	80
Conventional Water Treatment	<1	10	5	>80	67	50
Upgraded Water Treatment	None	2	1	100	93	90
Upgraded Water Treatment & Reverse Osmosis	None	<1	<1	100	>97	>90

A detailed analysis of the unit costs for the various treatment processes was conducted and is included in Appendix B. The Summary Table presents the costs and finished water qualities of a Base Case and eight other cases for different combinations of treatment. The following conclusions are based on data in the table:

1. Given the alternatives of providing AWT upstream of a conventional water treatment plant (Case 4) or continuing secondary treatment and instituting upgraded water treatment (Case 1), it is significantly lower in cost to upgrade the water treatment plant rather than the wastewater plant. This alternative (Case 1) also produces higher quality finished water. The larger the wastewater plant in relation to the water treatment plant, the more significant are the savings.

2. Upgrading the water treatment plant, even with effluent from a secondary plant 1-day upstream (Case 1) constituting 20 percent of the stream flows, results in higher finished water quality than would be produced by conventional treatment of typical stream water without a nearby municipal effluent discharge (see footnote 3 in Summary Table).

3. Upgrading the level of water treatment (Case 1) results in only a 2 to 14 percent increase in the Base Case wastewater plus water treatment costs but a very significant improvement in finished water quality.

4. Effects of the wastewater discharge on the ecosystem in the stream, eutrophication potential, and aesthetic considerations are more pertinant to whether secondary or advanced wastewater treatment should be provided than is the effect on quality of the downstream water supply.

5. The gain in finished water quality per unit cost by the addition of reverse osmosis to upgraded water treatment is much less than the gain per unit cost by the addition of the upgrading process to conventional water treatment.

An analysis of the costs to provide increased wastewater and water treatment plant reliability was also made. To provide essentially 100 percent reliability with standby treatment units and standby power, the total annual costs for wastewater treatment would increase by about 25 percent at 5 mgd and 13 percent at 25 and 50 mgd; the costs for water treatment would increase by 19 percent at 5 mgd, 8 - 12 percent at 25 mgd, and 4 - 8 percent at 50 mgd.

CASE HISTORIES

Three instances involving wastewater discharges above water supply intakes were reviewed. These case histories are included to illustrate the judgements that were made by local offícals in evaluating the merits of each case. In one case, Occoquan, Virginia, the evaluation is still in progress.

SUMMARY TABLE

TOTAL COST AND WATER TREATMENT PLANT PRODUCT WATER QUALITY

				Wastewater Treatment plus Water Treatment Costs ($/1,000 gallons water produced)			Water Treatment Plant Product Water Quality[3] (Concentration, mg/1)					
							For 20% Wastewater Reuse[4]			For 5% Wastewater Reuse[4]		
Case	Level of Wastewater Treatment	Level of Water Treatment	Separation Time (Days)	50 mgd WWTP & 5 mgd WTP[2]	5 mgd WWTP & 50 mgd WTP	25 mgd WWTP & 25 mgd WTP	BOD	COD	TOC	BOD	COD	TOC
Base	Secondary	Conventional	1.0	3.30	0.191	0.526	2	14	8	1.2	11	5.8
1	Secondary	Upgraded	1.0	3.36	0.217	0.560	ND	3.1	1.6	ND	2.3	1.2
2	Secondary	Upgraded plus Reverse Osmosis	1.0	4.01	0.785	1.15	ND	1.3	<1.6	ND	1.0	<1.2
3	Secondary	Conventional	2-30[1]	3.34	0.192	0.530	2	14	8	1.2	11	5.8
4	Advanced	Conventional	1.0	6.62	0.250	0.906	0.9	9.2	4.8	1.0	9.7	5.0
5	Advanced	Upgraded	1.0	6.67	0.277	0.940	ND	2.0	1.0	ND	2.1	1.0
6	Advanced	Conventional	2-30[1]	6.65	0.251	0.911	0.9	9.2	4.8	1.0	9.7	5.0
7	Advanced	Upgraded	2-30[1]	6.71	0.277	0.944	ND	2.0	1.0	ND	2.1	1.0
8	Advanced	Upgraded plus Reverse Osmosis	2-30[1]	7.37	0.845	1.54	ND	0.8	<1.0	ND	0.9	<1.0

[1] Costs are included for 1-day storage at the wastewater treatment plant.

[2] WWTP = Wastewater Treatment Plant, WTP = Water Treatment Plant, ND = None Detected.

[3] With no nearby upstream wastewater plant and with the assumed background stream quality, the water treatment plant product quality would be BOD <1 mg/1, COD = 10 mg/1, and TOC = 5 mg/1.

[4] Represents 20 percent or 5 percent of wastewater in total stream flow at the water intake.

Occoquan, Virginia - Several small secondary wastewater plants discharged their effluent for several years into the Occoquan Reservoir, a water supply reservoir for the Washington, D.C. area. The reservoir became highly eutrophic with the secondary effluents identified as the primary cause. It was expected that wastewater flows would eventually constitute 12 percent of the annual inflow to the reservoir and 46 percent of the July low flow. The alternative of exporting the secondary effluents below the water intakes was proposed but encountered public and agency opposition, primarily due to the high cost. A study by the State Water Control Board (SWCB) concluded that with AWT and continued discharge to the reservoir, the quantities of pollutants would be substantially reduced even at wastewater flows 10 times those then being experienced. The AWT alternative also offered substantial cost savings over the export alternative. The downstream water utility and the State Department of Health initially opposed this plan because of concerns about viruses; however, a supplemental review by the SWCB of the virus issue caused the opposition to be dropped. The SWCB adopted a policy calling for abandoning the 25 secondary plants in the basin and for AWT in a regional 10 mgd plant with discharge of the effluent to the water supply reservoir. The rigid weekly average effluent quality requirements include: BOD = 1 mg/l, COD = 10 mg/l, suspended solids = 0 mg/l, nitrogen = 1 mg/l, phosphorus = 0.1 mg/l, and coliform bacteria less than 2 per 100 milliliters. The policy requires specific treatment processes and backup treatment units to insure reliability. Regional review agencies concluded that the travel distance of 20 miles (travel time of 100-190 days) and effective downstream water treatment were adequate. The regional AWT plant was scheduled for start-up in early 1978.

Huron River, Michigan - In this case involving the Huron River, a 41 mgd wastewater discharge (nitrified, filtered effluent) was proposed about 14 miles upstream of the 4 mgd Flat Rock, Michigan water treatment plant. An environmental assessment concluded that at 7 day, 10 year dry flow conditions, the nitrate concentration in the Huron River would reach 10.25 mg/l, which is 0.25 mg/l above the drinking water standard, due to the wastewater discharge. The assessment also concluded that the combination of discharged organic material and chlorination could cause taste and odor problems. The wastewater flow constituted nearly 40 percent of the 7 day, 10 year dry flow. Any plant malfunctions were expected to cause serious water quality problems at the water intake and pose the threat of inadequately disinfected finished water. The Michigan Department of Health stated that if the wastewater project proceeded, the Flat Rock water plant would no longer be permitted to use the Huron River as a supply and the funding of an alternate supply for Flat Rock, including retirement of the existing bonds, should be included in the cost of the wastewater project. The proposed wastewater project was abandoned.

Passaic Basin, New Jersey - There are some 115 municipal and industrial waste discharges totaling 50 mgd, which constitutes about 60 percent of the flow at the Little Falls water supply intake for a 100 mgd plant serving 15 northern New Jersey communities. The water plant utilizes conventional treatment with powdered carbon additions during times of particularly poor water quality or upstream waste spills. The water utility admittedly depends upon the wastewater discharges to meet its quantity requirements. Although one of the most polluted rivers in the east, the Passaic is still serving satisfactorily as a major water supply. No viral diseases have been traced to the water supply. One of the main concerns of the water utility is the potential for significant trihalomethane concentrations. Consideration is being given to construction of granular carbon filters at the water treatment plant and use of AWT upstream, although neither appeared to be imminent in early 1978.

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LIST OF ABBREVIATIONS AND SYMBOLS

AWT -- advanced wastewater treatment
BOD -- biochemical oxygem demand
Btu -- british thermal unit
COD -- chemical oxygem demand
CT -- conventional water treatment
cu ft -- cubic feet
ft -- feet (foot)
gal -- gallon (s)
gpm -- gallons per minute
hr -- hour (s)
kg -- kilogram (s)
kw -- kilowatt
kwh -- kilowatt-hour
mg -- milligrams
mg/l -- milligrams per liter
mil -- million
mil gal -- million gallons
mgd -- million gallons per day
min -- minute (s)
ml -- milliliter
MPN -- most probable number
lb -- pound (s)
RO -- reverse osmosis
SS -- suspended solids
ST -- secondary treatment
TDS -- total dissolved solids
TOC -- total organic carbon
TU -- turbidity unit
µg/l -- micrograms per liter
UT -- upgraded water treatment
yr -- year (s)

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The material in Section 6 of this report on health considerations was prepared by Dr. Robert C. Cooper, School of Public Health, University of California, Berkeley, California.

SECTION 1

INTRODUCTION

PURPOSE AND SCOPE

The purpose of this report is to present information and guidelines for the location of proposed water supply intakes or proposed wastewater treatment facilities which may affect present or future water supply sources. The document is intended for use primarily by local planning and health officials. The purpose is not to provide a "cook book" for use in all situations. The material presented herein does not usurp the local decision making processes nor the need for careful evaluation by informed professionals at the local level on a case by case basis.

This study is limited to municipal wastewater discharges to surface waters upstream of water supply intakes. Water supply intakes from ground water sources or from lakes and reservoirs are not covered and ground water, industrial pollution and non point pollution are considered only as they affect stream water quality. Specific tasks are to define the items which should be considered in evaluating the location of water supply intakes including: (1) identification of data requirements, (2) identification of available stream modeling techniques, (3) capabilities and costs of water and wastewater treatment processes, and (4) health risks.

BACKGROUND

The Safe Drinking Water Act (PL 93-523) enacted on December 16, 1974 empowered the Administrator of the Environmental Protection Agency (EPA) to control the quality of the drinking water in public water systems through regulation and other means. The Act specified a three stage mechanism for the establishment of comprehensive regulations for drinking water quality.

1. Promulgation of National Interim Primary Drinking Water Regulations.
2. A study to be conducted by the National Academy of Sciences (NAS) within two years of enactment on the human health effects of exposure to contaminants in drinking water.
3. Promulgation of Revised National Primary Drinking Water Regulations based upon the NAS report.

National Interim Primary Drinking Water Regulations were promulgated on December 24, 1975 and July 9, 1976 and became effective on June 24, 1977. These regulations were based on the Public Health Service Drinking Water Standards of 1962, as revised by the EPA Advisory Committee on the Revisions and Application of the Drinking Water Standards. The regulations contain maximum contaminant levels (MCL) and monitoring requirements for microbiological contaminants (coliform bacteria), 10 inorganic chemicals, 6 organic chemicals, radionuclides and turbidity. Secondary Drinking Water Regulations were proposed by EPA on March 31, 1977.

The Interim Primary and Secondary Drinking Water Regulations established maximum contaminant levels for the following:

Interim Primary Regulations

Arsenic
Barium
Cadmium
Chromium
Fluoride
Lead
Mercury
Nitrate (as N)
Selenium
Silver
Endrin
Lindane
Methoxychlor
Toxaphene
2, 4-D
2, 4, 5-TP Silvex
Turbidity
Coliform Bacteria
Radionuclides

Secondary Regulations

Chloride
Color
Copper
Corrosivity
Foaming Agents
Hydrogen Sulfide
Iron
Manganese
Odor
pH
Sulfate
TDS
Zinc

The primary regulations are devoted to constituents affecting the health of consumers, while secondary regulations include those constituents which primarily deal with aesthetic qualities of drinking water. The primary regulations are applicable to all public water systems and are enforceable by EPA or the States which have accepted primacy. Secondary regulations are not Federally enforceable and are intended as guidelines for the States. The secondary regulations probably will be finalized by EPA during 1978.

The NAS summary report was delivered to Congress on May 26, 1977 and the full report was delivered on June 20, 1977. The summary report was also published in the Federal Register, Monday, July 11, 1977. The report[1] is available from the National Technical Information Service.* Based on the completed National Academy of Sciences Report and the findings of the Administrator, EPA will publish:

1. Recommended MCL's (health goals) for substances in drinking water which may have adverse effects on humans. These recommended levels will be selected so that no known or anticipated adverse effects would occur, allowing an adequate margin of safety. A list of contaminants which may have adverse effects, but which cannot be accurately measured in water, will also be published.
2. Revised National Primary Drinking Water Regulations. These will specify MCL's or require the use of treatment techniques. MCL's will be as close to the recommended levels for each contaminant as is feasible. Required treatment techniques for those substances which cannot be measured will reduce their concentrations to a

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*The NAS report is available from the U.S. Department of Commerce, National Technical Information Service, "Drinking Water and Health. Part I Chapters 1-5. A report of the Safe Drinking Water Committee", PB 270-422 "Drinking Water and Health. Part II, Chapters 6 and 7. A report of the Safe Drinking Water Committee", PB 270-420 level as close to the recommended level as is feasible. Feasibility is defined in the Act as use of the best technology, treatment techniques and other means which the Administrator finds are generally available (taking costs into consideration).

EPA proposes to amend the Interim Primary Drinking Water Regulations by adding requirements for other organic chemical contaminants. The proposed amendment was published in the Federal Register, Thursday, February 9, 1978 and consists of two parts:

1. The establishment of a MCL of 0.10 mg/l for total trihalomethane (THM), and
2. Treatment with granular activated carbon or equivalent for water systems serving populations greater than 75,000 and vulnerable to contamination by synthetic organic chemicals.

The principal concerns in the use of reclaimed wastewater for drinking are the potential adverse affects of small amounts of organics in the water. The volume, types, and associated long term health effects of the variety of constituents which may be found in small concentrations in municipal wastewater effluents is largely unknown. The Federal Drinking Water Regulations are minimum standards applicable to finished water from the tap; and are intended to apply to raw water derived from an essentially uncontaminanted source. State standards may be more stringent. There are no drinking water standards or criteria for the planned direct or indirect reuse of municipal wastewater for potable purposes.

The findings and recommendations of the National Academy of Sciences are pertinent to the subject of this report and frequent reference is made to the NAS study. However, as noted above, there are no requirements for reuse of reclaimed wastewater for potable purposes and the findings of the NAS study are not directly applicable to the reuse of wastewater.

The NAS study findings on biological indicators of pollution include the following statements relative to the reuse of wastewater:

> *"Bacteriological testing and observance of bacteriological standards are adjuncts to, not substitutes for, good-quality raw water, proper water treatment, and integrity of the distribution system. Application of the present coliform standards appears adequate to protect public health when raw water is obtained from a protected source, is appropriately treated, and is distributed in a contamination-free system.*
>
> *Current coliform standards are not satisfactory for water reclaimed directly from wastewater. Meeting current coliform standards for water reclaimed directly from wastewater, or for water containing several percent of fresh sewage effluent, is insufficient to protect public health. For such raw water supplies, new microbiological standards should be developed and applied as supplementary to coliform standards.*

There are federal funds available under Public Law 92-500, to aid communities in the construction of municipal wastewater treatment facilities.

Federal funds to support the construction of water supply facilities are limited to special circumstances, such as Farmers Home Administration loans for small communities. However, in recent months there has been considerable attention at the Federal level regarding financial support for water treatment systems. It should be noted that the water treatment industry has been a "pay as you go" concern and several industry leaders advocate continuing this process.

SECTION 2

BACKGROUND WATER QUALITY

It is necessary to establish some typical, or general, water quality conditions in streams and treated wastewater effluent before considering other factors in locating water supply intakes. Stream and wastewater quality vary from one location to another and vary with time at any given location. The intent of the following discussion is to review some of the available data on stream and treated effluent quality and to determine a general range of quality conditions.

STREAM WATER QUALITY

Stream water quality is affected by many natural and human factors. The climate, geological, soil and vegetative characteristics in the watershed all affect the quality of runoff to a stream. The type of rocks and soil affect both flowing stream water quality and the quality of ground water contributed to streams as base flow. Man's activities affect stream water quality through agricultural, industrial and municipal waste discharges and runoff from urban areas. There are also a variety of dynamic physical, chemical and biological processes at work in streams that affect water quality. All of these factors contribute in varying degrees to cause stream quality and flow rate to vary from one stream to another; and vary widely in some streams from one time to another throughout any particular period.

Longitudinal and seasonal variations of copper, chromium, lead and zinc in water, and sediments were measured in the 70 mile long Skeleton Creek, Oklahoma[2]. Samples were collected in February and August 1973. Turbidity increased downstream from 18.5 to 88 turbidity units (TU) in winter, and from 11.5 to 75 TU in summer. Copper, chromium and zinc concentrations in water varied as follows:

Concentration, μg/l

	Copper	Chromium	Zinc
Winter	2.9 - 13.9	ND - 3.0	6.7 - 31.1
Summer	0.3 - 3.5	ND - 1.0	ND - 3.6

ND = None Detected

Data collected and reported by Toth[3] illustrates the quality variations in four major streams in New Jersey. Table 1 shows water quality data for summer and winter in four New Jersey areas. The four areas vary in chemical composition of the soil. The effect of soils on water quality is further

TABLE 1

MEAN COMPOSITION OF SURFACE WATERS OF NEW JERSEY

(after Toth[3])

CONSTITUENT	CONCENTRATION, mg/l							
	SPRING FLOW				SUMMER FLOW			
			Southern				Southern	
	North	Central	Inner	Outer	North	Central	Inner	Outer
Calcium	18.3	11.7	11.0	1.0	31.3	15.8	11.5	0.90
Magnesium	9.0	4.6	3.5	0.6	15.3	6.5	2.9	0.40
Potassium	1.0	1.3	2.6	0.7	1.3	2.6	3.6	0.60
Sodium	n	n	n	n	6.1	9.0	9.6	3.0
Chloride	20.0	13.0	16.0	8.5	12.8	15.5	15.4	6.7
Aluminum	0.09	0.21	0.29	0.33	0.09	0.08	0.31	0.26
Chromium	0.002	0.003	0.003	0.001	0.011	0.013	0.013	0.025
Copper	0.013	0.020	0.018	0.018	0.024	0.030	0.022	0.024
Iron	0.07	0.26	0.54	0.51	0.12	0.72	2.0	0.60
Manganese	0.020	0.052	0.055	0.013	0.022	0.056	0.034	0.011
Nickel	0.005	0.005	0.009	0.002	0.008	0.016	0.017	0.011
Silicon	3.5	8.2	11.2	3.6	3.7	9.3	12.1	4.5
Strontium	0.040	0.026	0.027	0.004	0.129	0.065	0.021	0.002
Zinc	0.010	0.019	0.014	0.014	0.010	0.085	0.032	0.013

n = No Data

illustrated in Table 2. The Big Flat Brook flows through a calcareous soil area at site 1 while site 2 is in an area of acidic soils.

Table 3 summarizes the results of analyses reported by Kroner[4] for 1500 samples collected from surface waters in the United States during a five year period in the mid 1960's. Table 4 compares the quality of the St. Mary's and Cuyahoga Rivers from this data base. The St. Mary's River connects Lake Superior and Lake Huron and is considered a relatively clean stream that carries a heavy traffic of shipping but little or no industrial discharge. The Cuyahoga River receives numerous industrial discharges, especially from several metals industries, as it flows from Akron through Cleveland, Ohio to Lake Erie.

Samples were collected from 25 points along the 150 mile Neuse River in North Carolina in an attempt to correlate water quality with regional ground water and lithology.[5] The authors concluded that there were no correlations between the concentrations of major elements, sodium, chloride, calcium, and silica and the trace elements, barium, cobalt, silver. Also, there was no systematic change with location in the stream nor correlation with prevailing ground water lithology. It was concluded that the changes in concentrations were probably due to ground water variations and removal by biological and inorganic processes.

Another important consideration in assessing trace elements in natural waters is their variability in concentration with time. If this variability is large, it has implications for the number and frequency of samples required to determine average concentrations or loads. Some indication of this time variability is found in the analyses of samples collected from several points along the Ohio River. The ratio of the maximum to minimum concentration values obtained over a 5-year time span varied considerably from one point to another. The time variability was similar in the Allegheny and Monongahela Rivers at Pittsburgh to that encountered along the Ohio.[6] The average values obtained for alternate monthly periods for these two sampling points are shown in Table 5. These data show the differences in the two rivers just before they join to form the Ohio and indicate the changes in concentration of various inorganic constituents with time. It should be noted that there is no readily apparent systematic relationship between variations in concentration and season.

The data in Tables 1 through 5 illustrate the level and variability of inorganic chemicals in streams. The data on organic chemicals in streams is much more limited. Because of the public health implications of organics in drinking water, EPA initiated the National Organics Reconnaissance Survey (NORS) in November 1974 with three major objectives.

1. Determine the extent of the presence of the four trihalomethanes--chloroform, bromodichloromethane, dibromochloromethane and bromoform--in finished water, and to determine whether or not these compounds are formed by chlorination.
2. Determine the effect that raw water source and water treatment practices other than chlorination could have on the formation of these compounds.
3. Characterize, as completely as possible using existing analytical techniques, the organic content of 10 drinking waters. These 10 utilities represent five major categories of raw water sources used in the United States.

TABLE 2

COMPOSITION OF BIG FLAT BROOK WATER AT TWO SITES

(after Toth[3])

	CONCENTRATION, mg/l	
Constituent	Site 1 (Calcareous)	Site 2 (Acidic)
Calcium	35.0	11.2
Magnesium	7.5	2.4
Potassium	6.6	0.6
Sodium	3.7	2.5
Chloride	11.5	4.0
Aluminum	0.07	0.10
Chromium	0.002	0.002
Copper	0.016	0.002
Iron	0.08	0.03
Manganese	0.016	0.008
Nickel	0.006	0.001
Silicon	2.5	4.0
Strontium	0.500	0.030
Zinc	0.010	0.010

TABLE 3

SUMMARY OF SURFACE WATER QUALITY IN THE UNITED STATES*

(after Kroner[4])

Constituent	Concentration, mg/l			Frequency of Detection %
	MCL	Maximum	Mean	
Primary Standards				
Arsenic	0.05	0.336	0.064	5.5
Barium	1.0	0.340	0.043	99.4
Cadmium	0.01	0.120	0.0095	2.5
Chromium	0.05	0.112	0.0097	24.5
Fluoride	Varies	n	n	n
Lead	0.05	0.140	0.023	19.3
Mercury	0.002	n	n	n
Selenium	0.01	n	n	n
Silver	0.05	0.038	0.0026	6.6
Secondary Standards				
Copper	1.0	0.280	0.015	74.4
Iron	0.3	4.600	0.052	75.6
Manganese	0.05	3.230	0.058	51.4
Zinc	5.0	1.183	0.064	76.5
Chloride	250.0	n	n	n
Hydrogen Sulfide	0.05	n	n	n
Sulfate	250.0	n	n	n
TDS	500.0	n	n	n
Other				
Aluminum		2.760	0.074	31.2
Beryllium		0.001	0.0019	5.4
Boron		5.0	0.101	98.0
Cobalt		0.0028	0.048	2.8
Phosphorus		5.040	0.120	47.4
Molybdenum		1.500	0.068	32.7
Vanadium		0.300	0.044	3.4
Strontium		5.000	0.217	99.6

*Based on 1500 samples collected in the mid 1960's.

n = No Data

TABLE 4

WATER QUALITY SUMMARY

CUYAHOGA AND ST. MARY'S RIVERS*

(after Kroner[4])

CONSTITUENT	MCL mg/l	CUYAHOGA RIVER			ST. MARY'S RIVER		
		Maximum mg/l	Mean mg/l	Frequency of Detection %	Maximum mg/l	Mean mg/l	Frequency of Detection %
Primary Standards							
Arsenic	0.05	n	n	n	n	n	n
Barium	1.0	0.140	0.050	100	0.034	0.011	100
Cadmium	0.01	0.120	0.064	19	<0.010	<0.010	15
Chromium	0.05	0.015	0.011	19	0.007	0.003	20
Fluoride	n	n	n	n	n	n	n
Lead	0.05	0.030	0.028	12	0.007	0.005	53
Mercury	0.002	n	n	n	n	n	n
Selenium	0.01	n	n	n	n	n	n
Silver	0.05	<0.0045	<0.045	n	<0.004	<0.004	n
Secondary Standards							
Chloride	250	n	n	n	n	n	n
Copper	1.0	0.014	0.009	31	0.028	0.006	100
Hydrogen Sulfide	0.05	n	n	n	n	n	n
Iron	0.3	0.312	0.059	69	0.168	0.024	80
Manganese	0.05	0.900	0.285	88	0.285	0.004	60
Sulfate	250	n	n	n	n	n	n
TDS	500	n	n	n	n	n	n
Zinc	5.0	1.183	0.423	100	0.423	0.406	100
Other							
Aluminum		0.038	0.027	19	0.010	0.006	71
Boron		0.645	0.302	100	0.019	0.010	100
Molybdenum		0.030	0.027	12	0.012	0.009	33
Nickel		0.120	0.070	69	0.024	0.011	20
Strontium		0.245	0.148	100	0.022	0.015	100

* Data collected in mid 1960's

n = No Data

TABLE 5

TIME VARIATION OF CONCENTRATION (μg/l) OF SEVERAL TRACE ELEMENTS IN THE ALLEGHENY (A) AND MONONGAHELA (M) RIVERS AT PITTSBURGH

(after Shapiro, et al.[6])

Element	1964 Nov A	1964 Nov M	1965 Jan A	1965 Jan M	1965 March A	1965 March M	1965 May A	1965 May M	1965 July A	1965 July M	1965 Sept A	1965 Sept M
Barium	27	34	59	15	40	19	30	25	22	12	30	24
Boron	100	129	118	74	111	130	100	105	155	205	69	85
Copper	21	29	97	6	28	27	27	50	27	25	24	32
Nickel	20	<8	<8	<8	<13	<10	25	15	40	20	44	20
Strontium	118	143	45	53	28	47	50	65	100	90	120	130
Zinc	74	118	50	26	81	44	140	120	180	160	120	150

Eighty water utilities were chosen to determine the presence of six specific organics of particular concern: the four trihalomethanes, (chloroform, bromodichloromethane, dibromochloromethane and bromoform), carbon tetrachloride, and 1,2-dichloromethane. Selected in consultation with State water supply officials, these 80 utilities provide a reasonably representative sample of the Nation's community drinking water utilities that chlorinate their water, representing a wide variety of raw water sources, treatment techniques, and geographical locations. Survey findings indicate that chlorination results in the formation of the four trihalomethanes.

Results from the analysis of the raw waters are summarized below:

RAW WATER ANALYSIS
(Based on 80 samples)

	No. of Locations Detected	Range of Concentrations (μg/l)
Chloroform	49	<0.2 - 0.9 (16)*
Bromodichloromethane	7	<0.2 - 0.8 (11)*
Dibromochloromethane	1	-
Bromoform	0	-
Carbon Tetrachloride	4	<2 - 4
1,2-Dichloroethane	11	<0.2 - 3

*One location received raw water prechlorinated by a nearby industry. This water contained 16 μg/l of chloroform, 11 μg/l bromodichloromethane, and 3 μg/l dibromochloromethane. In 30 of the 80 locations surveyed, none of the six compounds were detected.

The NORS also involved selecting 10 of the 80 water utilities as sites representing five major categories of raw water sources for a more comprehensive survey of the organic content of their finished water. Two cities were selected for each basic type of water source: ground water, uncontaminated upland water, raw water contaminated with agricultural runoff, raw water contaminated with municipal waste, and raw water contaminated with industrial discharges. Three different analytical techniques were used to identify as broad a range of organic compounds as possible. The following summary shows the data for five utilities using streams as a raw water source.

City and Source	Type of Raw Water Source	No of Compounds Identified	No of Compounds Quantified
Seattle, WA Cedar River System	Uncontaminated Upland Water	31	13
Ottumwa, IA Des Moines River	Raw Water Contaminated with Agricultural Runoff	35	17
Philadelphia, Penn. Delaware River	Raw Water Contaminated with Municipal Waste	59	22

Table Continued

City and Source	Type of Raw Water Source	No of Compounds Identified	No of Compounds Quantified
Cincinnati, OH Ohio River	Raw Water Contaminated with Industrial Discharges	63	21
Lawrence, MA Merrimack River	Raw Water Contaminated with Industrial Discharges	30	14

Samples collected in the NORS were also analyzed for nonvolatile total organic carbon, and the 10 inorganics in the Primary Drinking Water Regulations. Some of these data were reported by Symons, et al.,[7] and the inorganic data are included in a report to Congress.[8] Thirty-five of the 80 locations surveyed use streams as a raw water source. The survey data for these 35 locations are summarized in Table 6.

EPA then expanded the organics monitoring effort and conducted the National Organics Monitoring Survey (NOMS) during March-July, 1976 and November 1976 - January 1977. The NOMS was a study of finished water quality conducted in 113 community water systems representing various types of sources and treatment processes. In several cases, additional studies were made of raw water sources to obtain background information. The following compounds and parameters were selected for study in the NOMS:

COMPOUNDS

Chloroform
1.2-Dichloroethane
Carbon Tetrachloride
Bromodichloromethane
Trichloroethylene
Dibromochloromethane
Bromoform
Benzene
Vinyl Chloride
Bis (2-chloroethyl) ether
p-Dichlorobenzene
1,2,4-Trichlorobenzene
2,4-Dichlorophenol
Pentachlorophenol
Polychlorinated Biphenyls
Fluoranthene
11, 12-Benzofluoranthene
3,4-Benzofluoranthene
1,12-Benzoperylene
3,4-Benzopyrene
Indeno (1,2,3-cd)Pyrene

PARAMETERS

Total Organic Carbon (Nonpurgeable)
Carbon Chloroform Extract
Ultraviolet Absorbance
Emission Fluorescence Scan

Results of the NOMS showed that the occurrences and concentrations of trihalomethanes in finished water were greater than for any other specific compounds or classes of compounds. The mean total trihalomethane concentration ranged from 0.068 to 0.120 mg/l and the median from 0.038 to 0.087 mg/l for the different sampling periods. Raw water contaminants occurred frequently at low concentrations in many supplies but the regularity of occurrence was

Table 6

NATIONAL ORGANICS RECONNAISSANCE SURVEY
Raw Water Quality Data

Location	Arsenic	Barium	Cadmium	Chromium	Cyanide	Flouride	Lead	Mercury	Nitrate	Selenium	Silver	Chloroform μg/l	Bromo-dichloro-methane μg/l	Dibromo-chloro-methane μg/l	Bromo form μg/l	1,2 Dichloro methane μg/l	Carbon Tetra-chloride μg/l	Nonvolatile Total Organic Carbon mg/l
	Inorganic Chemicals, mg/l											Organic Chemicals μg/l						
1. Lawrence, Mass. - Merrimack River	<.005	<.2	<.002	<.005	<.02	.1	<.005	<.0005	1.	<.005	<.01	<0.1	<0.2	NF	NF	NF	NF	3.7
5. Croton Reservoir - New York, N.Y.	<.005	<.2	<.002	<.005	<.02	<.1	<.005	.0006	1.	<.005	<.01	NF	NF	NF	NF	NF	NF	3.0
10. Hudson River - Rhinebeck, N. Y.	<.005	<.2	<.002	<.005	<.02	<.1	<.005	<.0005	2.	<.005	<.01	0.3	NF	NF	NF	3	NF	3.5
11. Delaware River - Philadelphia, Pa.	<.005	<.05	<.002	<.005	<.02	.9	.025	<.005	4.	<.005	<.01	0.2	NF	NF	NF	3	NF	2.6
12. Red Clay & White Clay Crk.-Claymont, Del,	<.005	<.05	<.002	<.005	<.02	1.1	.014	<.0022	7.	<.005	<.01	0.3	<0.4	NF	NF	NF	NF	2.8
14. Potomac River - Washington, D.C.	<.005	<.05	<.002	<.005	<.02	1.0	.005	<.0005	6.	<.005	<.01	<0.2	NF	NF	NF	NF	NF	1.8
16. Monongahela River - Pittsburgh, Pa.	<.005	<.2	<.002	<.005	<.02	1.4	.018	<.0005	3.	<.005	<.01	0.3	NF	NF	NF	NF	NF	0.9
19. Appomattox River - Hopewell, Va.												0.2	NF	NF	NF	NF	NF	4.2
20. Ohio River - Huntington, W.Va.	<.005	<.2	<.002	<.005	<.02	.1	.070	<.0005	2.	<.005	<.01	1	NF	NF	NF	<0.3	4	2.2
21. Ohio River - Wheeling, W. Va.	<.005	<.2	<.002	<.005	<.02	1.4	<.005	<.0005	3.	<.005	<.01	0.2	NF	NF	NF	<0.3	NF	3.2
24. Chattahoochee River - Atlanta, Ga.	<.005	<.05	<.002	<.005	<.02	.7	.025	<.0005	1.	<.005	<.01	<0.2	NF	NF	NF	<0.3	NF	1.3
27. Tennessee River - Chattanooga, Tenn.	<.005	<.05	<.002	<.005	<.02	1.0	.010	.0028	1.	<.005	<.01	0.9	NF	NF	NF	NF	NF	1.1
29. Cumberland River - Nashville, Tennessee	.005	<.2	<.002	<.005	<.02	1.3	.010	<.0005	2.	<.005	<.01	<0.1	NF	NF	NF	NF	NF	1.2
36. Detroit River Intake at head of Belle Is - Detroit, Mich.	<.005	<.2	<.002	<.005	<.02	1.1	<.005	<.0005	1.	<.005	<.01	<0.2	NF	NF	NF	0.5	NF	2.6
38. Mississippi River - St. Paul, Minn.	<.005	<.2	<.002	<.005	<.02	1.3	.010	<.0005	2.	<.005	<.01	<0.2	NF	NF	NF	NF	NF	7.9
40. Scioto River - Columbus, Ohio	<.005	<.2	<.002	<.005	<.02	1.4	.020	<.0005	15.	<.005	<.01	0.1	NF	NF	NF	NF	NF	6.8
43. Swift Run Lake - Piqua, Ohio	<.005	.03	<.002	<.005	<.02	.2	<.005	<.0005	8.	<.005	<.01	NF	NF	NF	NF	NF	NF	0.9
47. Bayoulafourche - Houma, La.	<.005	.1	<.002	<.005	<.02	.1	.026	<.0005	<1.	<.005	<.01	NF	NF	NF	NF	NF	NF	5.4
48. Ouachita River - Camden, Ark.	<.005	<.05	<.002	<.005	<.02	1.1	.013	<.0005	1.	<.005	<.01	NF	NF	NF	NF	NF	NF	3.1
49. Sabine River - Logansport, Louisiana.	<.005	<.2	<.002	<.005	<.02	.1	.026	<.0005	<1.	<.005	<.01	0.7	NF	NF	NF	NF	NF	5.3
52. Rio Grande River - Brownsville, Tex.												NF	NF	NF	NF	NF	NF	4.7
53. Elm Fork, Trinity River - Dallas, Tex.	<.005	<.2	<.002	<.005	<.02	1.0	.014	<.0005	2.	<.005	<.01	<0.1	NF	NF	NF	NF	NF	3.4
55a. Des Moines River - Ottumwa, Iowa	<.005	.07	<.002	<.005	<.02	1.3	.023	<.0005	8.	<.005	<.01	<0.2	NF	NF	NF	NF	NF	4.1
55b. Des Moines River - Ottumwa, Iowa												NF	NF	NF	NF	NF	NF	4.9
56. Nodaway River - Clarinda, Iowa	<.005	<.05	<.005	<.005	<.02	.3	.025	<.0005	1.	<.005	<.01	<0.2	NF	NF	NF	NF	NF	3.5
57. Mississippi River - Davenport, Iowa	<.005	<.05	<.002	<.005	<.02	1.1	.012	<.0005	<1.	<.005	<.01	0.4	NF	NF	NF	NF	NF	6.5
58. Kansas River - Topeka, Kan	<.005	<.2	<.002	<.005	<.02	1.2	<.005	<.0005	1.	<.005	<.01	<0.4	NF	NF	NF	NF	NF	3.4
59. Mississippi River - Cape Girardeau, Mo.	<.005	.08	<.002	<.005	<.02	1.1	<.005	<.0005	5.	<.005	<.01	0.2	0.8	NF	NF	0.2	NF	4.5
60. Missouri River - Kansas City, Mo.	<.005	.03	<.002	<.005	<.02	.1	<.005	<.0005	3.	<.005	<.01	NF	NF	NF	NF	NF	NF	3.4
61. Missouri River - St. Louis, Mo.	<.005	.01	<.002	<.005	<.02	1.0	<.005	<.0005	3.	<.005	<.01	NF	NF	NF	NF	0.3	NF	3.4
63. Red Lake - Grand Forks, N.D.	<.005	<.2	<.002	<.005	<.02	1.3	<.005	<.0005	2.	<.005	<.01	NF	NF	NF	NF	NF	NF	9.2
65. Arkansas River - Pueblo, Colo.	<.005	<.2	.004	<.005	<.02	1.6	<.005	<.0005	<1.	<.005	<.01	<0.2	NF	NF	NF	NF	NF	1.8
69. Salt and Verde Rivers - Phoenix, Ariz.	.005	<.05	<.002	<.005	<.02	.4	.017	<.0005	<1.	<.005	<.01	<0.2	NF	NF	NF	NF	NF	1.0
76. Cedar River Impoundment - Seattle, Wash.	<.005	.03	<.002	<.005	<.02	1.1	<.005	<.0005	<1.	<.005	<.01	<0.2	NF	NF	NF	NF	NF	0.9
79. Willamette River - Corvallis, Ore.	<.005	<.2	<.002	<.005	<.02	1.2	.024	<.0005	<1.	<.005	< 01	NF	NF	NF	NF	NF	NF	1.0
Median	<.005	0.15	<.002	<.005	<.02	2.0	.01	<.0005	2.	<.005	<.01	<0.2	NF	NF	NF	NF	NF	3.3
Range	<.005-.005	0.01 to 0.1	<.002-.004	<.005	<.02	<.1-1.6	<.005-.070	<.0005-.005	<1-15	<.005-<.005	<.01	NF to 1.0	NF to 0.08	NF	NF	NF to 3	NF to 4	0.9 to 9.2

NF=None Found

not nearly as great as for trihalomethanes. The general parameters (total organic carbon, carbon chloroform extract, ultraviolet absorbance and emissions fluorescence scan) did not correlate with the occurrences of specific organic compounds.

The U.S. Geological Survey[9] collected samples during 1969-1970 for organic carbon and nitrogen analysis from the following six streams: (1) Neuse River near Goldsboro, N.C., (2) Brazos River at Richmond, Texas, (3) Ohio River at Metropolis, Ill., (4) Mississippi River near Luling Ferry, La., St. Francisville, La., and Belle Chasses, La., (5) Missouri River at Nebraska City, Nebr., and (6) Sopchoppy River near Sopchoppy, Fla.

Results of analyses of water and suspended sediment samples are summarized in Table 7. Average dissolved organic carbon (DOC) concentrations in the Brazos, Mississippi, Missouri, and Ohio Rivers are of similar magnitude (between 3 and 4 mg/l), but the Neuse River is somewhat higher at 7.1 mg/l. DOC concentrations in the Mississippi, Neuse, and Ohio Rivers are relatively constant throughout the year, whereas DOC concentrations for the Sopchoppy River are highly variable and show no definite trends within each season of the year. DOC concentrations show a definite trend to increase during the winter months in the Brazos and Missouri Rivers.

DOC concentrations were found to be independent of stream discharge. Based on the sampling program, the authors concluded that:[8] (1) DOC concentration at any given time is a result of several dynamic processes within a given stream. Sorption, desorption, scouring of the bed material, growth of organisms, decomposition of organic litter, seasonal sources of organic substances, point sources of organic contamination, and other factors are important considerations in evaluating dissolved and suspended organic carbon concentrations, (2) the concentration of DOC within a given stream varies with season and sources of contamination in a repeating pattern which is somewhat characteristic of the stream.

Based on a review of several investigations, the concentrations of organic carbon as measured by TOC in natural surface waters was reported to vary from 1.0 to 50 mg/l with average concentrations in the 10 to 15 mg/l range.[10]

All of these studies and data indicate that there can be large differences in the concentrations of trace organic and inorganic contaminants as well as constituents commonly found in waters such as chloride, sulfate, calcium, and sodium. Variations can occur within relatively short distance in streams and such variations often occur in an unsystematic and nonpredictable manner.

WASTEWATER EFFLUENT QUALITY

The quality of municipal wastewater effluent is influenced by several factors including: (1) type of treatment system, (2) quality of water supply (primarily affects TDS), (3) water use, (4) quantity and quality of industrial waste discharges, and (5) infiltration into collection system.

The concentrations of inorganic chemicals in several secondary treatment plants are summarized in Table 8. These data indicate that some secondary effluents contain inorganic chemicals that exceed MCL's specified in the Drinking Water Regulations. However, the higher values are in plants that receive significant industrial discharges. Many municipal treatment plants receive a significant percentage of industrial wastewater. Industrial waste ordinances and pretreatment requirements in force or being established by municipal treatment systems will reduce the impact of industrial discharges.

TABLE 7

AVERAGE CARBON AND NITROGEN CONCENTRATIONS IN WATER AND SUSPENDED SEDIMENT DURING 1969-70

(after Malcolm and Durum[9])

Stream	DOC (mg/1)	SOC (mg/1)	Percentage SOC in Sediment	Percentage KN in Sediment	SOC/KN ratio or C/N ratio	Percentage SIC in Sediment
Brazos	3.3	3.6	4.67	0.65	7.2	1.30
Mississippi	3.4	3.8	2.28	.28	8.1	.15
Missouri	4.6	20	3.12	.35	8.9	.34
Neuse	7.1	2.8	9.00	1.30	6.9	0
Ohio	3.1	1.8	3.93	.49	8.0	.20
Sopchoppy	27	1.6	35.3	4.04	8.7	0

DOC = Dissolved Organic Carbon
SOC = Suspended Organic Carbon
KN = Kjeldahl Nitrogen
SIC = Suspended Inorganic Carbon
C = Carbon
N = Nitrogen

TABLE 8

SECONDARY EFFLUENT QUALITY

Primary Regulations	MCL mg/l	Colorado TF[11] mg/l	Colorado AS[11] mg/l	Denver[12] AS mg/l	Los Angeles[13] AS mg/l	Los Angeles[14] AS mg/l	Orange County, CA[15] TF mg/l	San Francisco[16] AS mg/l	Pennsylvania[17] AS mg/l	Indiana[17] AS mg/l	New York[18] AS mg/l	Massachusetts[19] AS & TF mg/l	TF and AS Effluent Range mg/l
Arsenic	0.05			0.003	0.02		0.002						0.002 - 0.02
Barium	1.0			0.192	0.18		0.082						0.082 - 0.192
Cadmium	0.01	0.0014	0.0012	<0.001	0.01	0.007	0.009	0.0026	0.018		0.016		0.001 - 0.018
Chromium	0.05	0.049	0.060	0.050	0.08	0.050	0.204	0.209	0.031	0.04	0.16		0.031 - 0.209
Fluoride	1.4 - 2.4		0.5	1.1	1.0		0.7						0.5 - 1.1
Lead	0.05	0.12	0.056	0.082	0.013		0.036	0.019	0.022	0.27			0.017 - 0.082
Mercury	0.002				<0.0001	0.056	0.0004						<0.0001 - 0.0004
Nitrate (as N)	10			<1	3.5		<1						<1 - >10
Selenium	0.01			0.008	0.018	0.0002	0.007						0.0002 - 0.018
Silver	0.05	0.004	0.005	0.008	0.004	0.05	0.004		0.070				0.004 - 0.070
Secondary Regulations													
Copper	1.0	0.112	0.123		0.21	0.015	0.291	0.019	0.056	0.06	0.27		0.013 - 0.053
Iron	0.3	0.764	0.773		0.02	0.058	0.190	0.597					0.02 - 1.33
Manganese	0.05	0.038	0.041		<0.05	0.026	0.038	0.087		0.09			0.026 - 0.122
Zinc	5.0	0.193	0.20		0.10	0.102	0.308	0.298	0.229	0.27	0.41		0.10 - 0.583
Other													
Total Organic Carbon	None	35					25					10 - 50	10 - 50

TF = Trickling Filter
AS = Activated Sludge
11 thru 19 = References

Industrial discharges and the local requirements for pretreatment are important considerations in any waste discharge-water intake case. Wastewater from strictly residential areas does not normally contain inorganic chemicals or radioactive material that exceed the Primary Drinking Water Regulations.

The organic material in municipal wastewater is a mixture of a multitude of compounds that are only partially known. The three main broad classes of organics in municipal wastewater--fats, carbohydrates and proteins--are usually considered removable by primary and secondary biological treatment, protein being somewhat less readily removed than fats and carbohydrates. A properly operating biological treatment plant is capable of producing secondary effluent from residential wastewater with a soluble COD of 30 to 50 mg/l and a soluble BOD of 1 to 2 mg/l. The data on TOC levels in wastewater is scarce but the available information indicates that secondary effluent concentrations are in the 30 to 50 mg/l range. Concentration of foaming agents, as indicated by tests for MBAS, in secondary effluent is typically in the 2 to 4 mg/l range.

There is little data reported for wastewater on the six organic compounds in the Primary Drinking Water Regulations. Recent tests in Orange County, California on trickling filter effluent that contains about 20 percent industrial wastes, found that concentrations of all six compounds were below detectable limits.

A study in 1961 of secondary effluent from five treatment plants in the United States did not identify 65 percent of the average COD of 100 mg/l.[20] Trickling filter effluent from the Haifa, Israel municipal wastewater treatment plant was analyzed for total organic content and the results reported as percent of total COD.[21] The total COD was about 180 mg/l and the organics were classified as: 40 to 50 percent humic substances (humic, fulvic and hymathomelanic acids); 8.3 percent ether extractables; 13.9 percent anionic detergents; 11.5 percent carbohydrates; 22.5 percent proteins; and 1.7 percent tannins. A later, more extensive study including activated sludge effluents was conducted[22] and the results are summarized in Table 9. Another study found 60 percent of the organics in secondary effluent had molecular weights less than 700 and 25 percent had apparent molecular weights greater than 5,000.[23]

In one study of municipal wastewater, 77 organic compounds were detected in the primary effluent and 38 in the secondary effluent and apparently some additional compounds were being produced during secondary treatment.[24] The concentrations of individual compounds in the secondary effluent were estimated to be less than 20 μg/l. It was found in another study[25] that soluble organics are produced in biological treatment that are more refractory to further treatments than the organics in raw sewage. It was hypothesized by these same investigators that the residual organics not removed by activated carbon are intermediate breakdown products of protein and that these are most likely the protein that originates from the cell walls of microorganisms present in biological treatment processes.

The fate of the organics in the chlorination process is of particular concern. A study published in 1973 found that chlorine-containing stable organic constituents are present after chlorination of effluents from domestic sewage treatment plants.[26] Over 50 chlorine-containing organic compounds were separated from chlorinated secondary effluents. Seventeen of these compounds were tentatively identified and quantified at the 0.5 to 4.3 μg/l level. The chlorination yield (the portion of the chlorine dose associated

TABLE 9

ORGANICS IN SECONDARY EFFLUENT

(after Manka, et al.[22])

DISTRIBUTION OF ORGANIC GROUPINGS

Organic groupings and fractions	Percent of total COD Municipal wastewater high rate trickling filter	Municipal wastewater stabilization pond	Domestic wastewater extended aeration activated sludge
Proteins	21.6	21.1	23.1
Carbohydrates	5.9	7.8	4.6
Tannins and lignins	1.3	2.1	1.0
Anionic detergents	16.6	12.2	16.0
Ether extractables	13.4	11.9	16.3
Fulvic acid	25.4	26.6	24.0
Humic acid	12.5	14.7	6.1
Hymathomelanic acid	7.7	6.7	4.8

MOLECULAR WEIGHT DISTRIBUTION OF HUMIC SUBSTANCES

Molecular weight range	Percent of humic compound present Fulvic acid	Humic acid	Hymatho-Melanic acid
<500	27.5	17.9	4.5
500-1000	7.8	6.2	12.2
1000-5000	35.7	29.4	48.0
5000-10,000	15.3	7.8	28.0
10,000-50,000	9.4	36.7	7.5
>50,000	4.3	2.0	0

with chlorine-containing stable organic compounds at the end of the chlorination reaction period) was approximately 1.0 percent for secondary effluents which had been chlorinated with 3.2 mg/l chlorine to a residual of 1 mg/l at contact times of 15 to 45 minutes. The chlorination yield was approximately constant with respect to chlorine dosage (in the range studied) but increased with increasing reaction time. Chlorination yields were approximately the same for both primary and secondary effluents. Essentially the same effects were obtained by chlorination with either gas or hypochlorite solution. In addition to the 17 chlorine-containing compounds that were identified, 32 stable organic constituents were identified and 23 of these were quantified at 2 to 190 µg/l levels in the effluents from domestic primary sewage treatment plants. Nine stable organic constituents were identified and eight of these were quantified at 5 to 90 µg/l levels in the effluents from domestic secondary sewage treatment plants.

Some 30 chlorinated compounds, primarily aromatic derivatives, have been attributed to chlorination of secondary effluent with chlorine dosages of 1,500 mg/l.[27] Preliminary data indicated total organic-bound chlorine to be 3,000 to 4,000 µg/l with these large chlorine dosages.

Another study found that when chlorine was added to activated sludge effluent in excess of the ratio to achieve breakpoint chlorination, chloroform was formed in less than two minutes, and the concentration increased with reaction time.[28] For example, at the end of two minutes reaction time, the chloroform concentration was 30 µg/l and increased to 262 µg/l; at the end of 24 hours. When chlorine was added at or below the ratio required to achieve breakpoint, only small amounts of chloroform were formed with little or no increase in concentration with reaction time: chloroform concentration increased from 6.0 µg/l after two minutes reaction time to 10.8 µg/l after 24 hours.

SUMMARY - BACKGROUND WATER QUALITY

The U.S. Geological Survey operates a National Stream Quality Accounting Network (NSQAN) that involves the collection of data from 345 stream sampling stations in the United States. Typical concentrations of the constituents in the Drinking Water Regulations are shown in Table 10 for streams and secondary effluent. These values are based on a review of the data discussed in this section and data from the NSQAN system. The typical values shown for streams and secondary effluent are considered representative of unpolluted streams and municipal wastewater, and of course, may vary due to local conditions.

These data summarized in Table 10 indicate that typical stream water quality is well below the Drinking Water Regulations MCL for all inorganic and organic chemicals. Typical municipal secondary effluent is also expected to be at or below the MCL for specific inorganic and organic chemicals listed in the regulations. However, organic contaminants in wastewater as measured by color, foaming and odor, exceed the regulations. Also, although there is no MCL for organics as measured by chemical oxygen demand (COD) or total organic carbon (TOC), the levels of these organic parameters are usually substantially higher in municipal wastewater than in streams. Therefore, the primary area of concern is the effect of municipal wastewater on the content of organic material in streams.

TABLE 10

BACKGROUND WATER QUALITY

(mg/l except as noted)

PARAMETERS	DRINKING WATER MCL	STREAM			SECONDARY EFFLUENT
Primary Regulations		Low	High	Typical	Typical
Arsenic	0.05	<0.005	0.340	0.005	0.005
Barium	1	0.03	0.340	0.15	0.1
Cadmium	0.010	<0.002	0.120	0.002	0.001
Chromium	0.05	<0.005	0.120	0.005	0.05
Fluoride	1.4 to 2.4[1]	0.1	1.6	0.2	0.7
Lead	0.05	<0.005	0.140	0.015	0.02
Mercury	0.002	<0.0005	0.005	0.0005	0.0002
Nitrate (as N)	10	<1	3.4	1	1
Selenium	0.01	<0.001	0.060	0.001	0.001
Silver	0.05	<0.001	0.038	0.003	0.005
Endrin	0.0002	ND	0.00006	<0.00001	ND
Lindane	0.004	ND	0.0002	<0.00001	ND
Methoxychlor	0.1	ND	0.0001	<0.00001	ND
Toxaphene	0.005	ND	ND	ND	ND
2, 4-D	0.1	ND	0.0031	<0.00005	ND
2, 4, 5-TP Silvex	0.01	ND	0.0017	<0.00003	ND
Turbidity, TU	1[2]	<15	1×10^7	50	25
Coliform Bacteria (colonies/100 ml)	1[3]	<100	1.5×10^5	1,000	1×10^7
Secondary Regulations					
Copper	1	<0.0002	3.8	<0.0003	0.1
Iron	0.3	<0.05	7.8	0.12	0.2
Manganese	0.05	<0.1	36.0	0.25	0.05
Zinc	5	<0.02	6.5	0.07	0.5
Color, units	15				60
Foaming Agents (as MBAS)	0.5				1.5
Odor, TON	3				40
Other					
Trihalomethane	0.10[4]	ND	0.0011	ND	0.005
COD	None	2.5	125	30	100
TOC	None	1	50	10	40

[1] Varies with average annual maximum daily air temperature

[2] Monthly average

[3] Monthly average, membrane filter technique

[4] Proposed MCL

ND = None Detected

SECTION 3

FATE OF CONTAMINANTS IN STREAMS

There are many factors that can affect the concentration of contaminants in streams. These factors are discussed in several books and reports including the following: "Environmental Chemistry", by Manahan,[29] "Aquatic Chemistry", by Stumm and Morgan,[30] Trace Metals and Metal-Organic Interactions in Natural Waters", edited by Singer,[31] and "Aqueous Environmental Chemistry of Metals", edited by Rubin.[32]

Contaminants may be contributed to streams from several sources including: (1) soil and rock, (2) waste discharges, (3) storm runoff, (4) precipitation and atmospheric fallout, and (5) biological organisms. Flowing streams are dynamic systems and the chemical and biochemical reaction rates are such that equilibrium conditions are only slowly, if ever, attained. The organic and inorganic chemicals of concern in water supply interact with one another and with other materials and organisms in various chemical and biochemical reactions. Reactions that can take place in streams to decrease, or in some cases increase, the concentration of contaminants include: (1) precipitation, (2) complexation, (3) oxidation-reduction, (4) ion exchange, (5) adsorption and/or absorption, often termed "sorption", (6) flocculation, and (7) biological uptake and/or release.

Contaminants and other material are present in water in suspended, colloidal or dissolved form. Generally, material less than 0.45 micron in size is considered to be dissolved. This is a somewhat arbitrary division and colloidal particles range from less than 0.45 micron to about 1 micron. Most chemical reactions affecting natural water systems occur at the solution-solid interface or within the cells of bacteria or algae. Because of their large surface to volume ratio colloidal particles suspended in water are particularly important in chemical reactions. Colloidal particles are capable of changing contaminant concentrations through sorption, exchange and flocculation actions. Clay minerals are important colloids in many streams.

PHYSICAL FACTORS

The important stream physical characteristics include velocity, depth, turbulence, degree of mixing, temperature, turbidity, changes in cross section and bottom characteristics such as slope, type of material and sorptive capacity. The effects of some of these parameters are so interrelated that their relative importance is difficult to determine. For example, the bottom slope affects the depth and the velocity of the stream, and turbulence is affected by all three.

The degree of mixing in a stream is a very important parameter and is determined by the physical characteristics. Mixing in a stream can occur vertically, laterally or longitudinally. Vertical mixing normally occurs within a few tenths of a mile. Density gradients from temperature differences in the stream tend to overcome vertical mixing but this rarely occurs. Lateral mixing is normally complete within miles and increases with the number of relatively sharp reverse bends in the stream reach. Longitudinal mixing, caused by variations in cross section and changes in direction that permit areas of quiet water and eddy currents, may require tens of miles as compared to miles for laterial and tenths of miles for vertical mixing.

Other parameters determined by the physical characteristics of the stream are the reaeration rate and solids deposits. The reaeration rate is a function of velocity and depth and increases with increasing velocity. Sedimentation of suspended particles is dependent on the degree of turbulence in the stream. Settled solids can be scoured off the bottom and resuspended during periods of increased flow. This raises the stream turbidity and increases oxygen demand.

PRECIPITATION AND COMPLEXATION

In general, all the constituents of a natural chemical system including trace metals, ions, and inorganic and organic compounds are related to each other through complex formation and solid precipitation reactions. The variation of any constituent will give rise to variations in at least some of the other constituents. The organic component of fresh natural water is poorly known analytically; its complexing properties are under investigation and are only hypothesized in many cases.

The complexation of metal ions with either naturally occuring organic material or organics in waste discharges may be important reactions. Complex formation is the combination of metal cations with molecules or anions to form a coordination or complex compound. There is some indirect evidence that complexing agents play an important role in the form of the metal concentration in treated wastewater. It is possible that pollutant complexing agents in flowing streams play an important role in transporting heavy metals and preventing their removal by conventional water treatment.

Many of the metal ions found in natural waters, particularly those found at trace levels form strong complexes with a variety of chemical species. The formation of complex compounds may have several effects such as: (1) the formation of insoluble compounds may remove metal ions from solution, (2) complexation may also solubilize metal ions from otherwise insoluble metal compounds, and (3) strong complexation may shift oxidation-reduction potentials. Little data has been reported regarding levels of complexing agents and stable metal complexes in natural waters. Complexing agents are not normally determined in water analyses.

Humic and fulvic acids are probably the most important naturally occuring complexing agents. These acids are rather loosely defined and refer to a family of compounds, similar in structure and chemical properties, formed during the decomposition of vegetation. They have the ability to strongly bind metal ions and they are found in both water and soil. Synthetic complexing agents such as sodium tripolyphosphate, sodium ethylenediaminetetraacetate (EDTA), sodium citrate and sodium nitrilotriacetate (NTA) are produced in large quantities and almost certainly find their way into streams through waste discharges. NTA may also solubilize heavy metals from sediments on stream bottoms depending on pH, bicarbonate concentration, calcium concentration and nature of the sediments.

In addition to their phosphorus content, one of the factors which contributes to the fertilizer value of polyphosphate fertilizers is their capacity to act as complexing agents, thus solubilizing micronutrient ions from soils and making essential metals more available to plants. Therefore, it is possible that polyphosphates present in runoff from fertilized soils may act as complexing agents in some waters prior to hydrolysis of the polyphosphates to orthophosphate.

IMPORTANCE OF CLAY MINERALS AND OTHER SUSPENDED MATERIAL

Clay minerals are among the most common suspended matter found in natural waters. In many streams, clays are probably the most important mineral solids present in colloidal suspension or as sediments because:

1. Clay minerals can fix dissolved chemicals in water and therefore exert a purifying action. The ability of clays to exchange cations is an important phenomenon having an impact on the availability of trace level metal nutrients in water.
2. Because of their high surface area and other properties, clays also may sorb organic compounds such as pesticides, herbicides, and are important in the transport and removal of organic pollutants in streams.
3. It is also believed that some microbiological processes occur at clay mineral surfaces, thus clays may participate in the degradation process for organic materials.

The sorption of organic compounds by montmorillonite has been investigated in some detail; the sorption of the herbicide, 2, 4-D, on montmorillonite, kaolinite, and illite was studied. The sorption process was found to be relatively slow, requiring several hundred hours to reach equilibrium. It was concluded that the overall process must be relatively complicated involving sorption onto the clay surface and subsequent diffusion of the herbicide into the clay.

One study found that there are regional differences in the concentrations of chromium, silver, molybdenum, nickel, cobalt and manganese and suspended sediments in streams.[33] The sediments of the Mississippi and the rivers west of it draining into the Gulf of Mexico resembled average shale in composition, while the rivers east of the Mississippi are considerably higher in metals concentration. The suspended material in the central rivers is rich in montmorillonite, whereas eastern rivers carry more organic matter, illite and kaolinite. The cation exchange capacity (CEC) of suspended clays in eastern streams is generally in the range of 14 to 28 milliequivalents per 100 grams, whereas the CEC of central streams ranges from 25 to 65 milliequivalents per 100 grams. Although the central streams have the higher CEC, they carry a relatively lower load of most trace metals than do the eastern streams. Therefore, the degree of trace metal transport is not strictly a function of CEC, but perhaps is due to a greater amount of trace element rich soil and industrial discharges. The correlation between suspended organic material and suspended trace metal levels was found to be quite low. Therefore, it appears that suspended trace metals are carried primarily by suspended mineral materials. Generally, high levels of suspended manganese were found to be associated with high levels of other suspended trace metals. A wide range of values for the various metals was found in the study. Of the 20 rivers examined, the suspended solids load ranged from 12 to 954 mg/l and the following ranges of specific trace metals were found:

Constituent	Concentration range, mg/l
Chromium	37 - 460
Silver	0.3 - 14
Molybdenum	5 - 44
Nickel	6 - >500
Manganese	320 - 1500

Another study[34] investigated the sorption of lindane by untreated lake sediments. It was found that the degree of lindane adsorption was determined by the following factors of decreasing effect:

Sediment Concentration
Sediment and Organic Content
Lindane Concentration
Sediment Clay Content
Lindane to Sediment Ratio

Lindane is a non-ionic compound, therefore its sorption by sediments probably involves phenomenon such as Ven der Waals forces and hydrogen bonding.

SECTION 4

STREAM MODELING TECHNIQUES

A stream model is a set of mathematical equations that are used to represent the relationships that exist between various elements of the system. Depending on the information desired, the mathematical model may range from a few simple equations that can be solved by hand computation to hundreds of complex equations that can be solved only through the use of a digital computer.

The previous section discussed the variety and complexity of reactions that occur in streams and indicated several stream mechanisms that impact the concentration of pollutants. The dynamic nature of streams and complexity of the reactions make stream modeling a difficult task. It is impossible to describe the chemistry of a natural aquatic system based on acid base relationships, solubility and complexation, equilibrium constants, oxidation-reduction potential, pH, and other chemical parameters; therefore, models must be simplified; nevertheless, some models may provide a general understanding of aquatic systems and give some insight into the conditions that determine chemical reactions and products in flowing streams.

Many of the first models developed were concerned only with dissolved oxygen (DO) and BOD concentrations at various distances from the pollution source.[35-41] The well-known Streeter-Phelps equation is of this type[35] and many of the subsequent models have followed the same empirical form.[36-39] Kenkel and Orlob[40] attempted to explain reaeration in terms of longitudinal dispersion and Thackston and Kenkel[41] incorporated hydraulic slope as an additional influencing factor. In an attempt to verify or test these models, Tsivoglou and Neal[42] used a gaseous tracer procedure to measure stream aeration capacity. Their results include a number of suggestions and considerations concerning stream modeling. Since none of the models tested were capable of predicting reaeration capacity within acceptable limits of error, Tsivoglou and Neal presented an energy dissipation model based on the usual one-dimensional energy equation that gave good results for the rivers studied.

Hoover and Arnoldi[43] developed a computer model which simulates the BOD distribution in the Connecticut River by incorporating the best information available that describes physical conditions such as flow volumes and sounding depths, and the latest pollution data describing DO, BOD and temperature.

Gundelach and Castillo[44] developed a model that includes the possibility of anaerobic conditions in polluted waters. The equations used attempt to describe mathematically the aerobic decay of oxygen-demanding substances (mainly organic matter) under anaerobic conditions. The results of the computer simulations for this model indicate more realistic levels for BOD removal throughout the anaerobic reach than those computed by the unrestricted application of a general aerobic model.

A model developed by Haith and Chapman[45] evaluates costs and water quality, in terms of DO concentration, for the screening of wastewater treatment alternatives. The objective of this model is to identify cost-effective wastewater management combinations that meet the requirements of Best Practicable Waste Treatment Technology. The model can provide simulation of discharge alternatives to rivers or can be used to identify treatment strategies with cost-effective potential.

A paper by Bath, et al.,[46] presents a model that describes dispersion of conservative contaminants injected into streams. The model is based on mass-transport mechanisms that pertain to open-channel flow in streams and represents quite accurately the concentration profile downstream from instantaneous pollution loadings. The model contains terms to describe molecular diffusion, due to concentration gradients, eddy diffusion, due to the gross corrective motion of the fluid, and sorptive interactions with the stream bed or quiescent pools. Experimental results obtained from Soldier Creek, Kansas showed good correlation with model predictions.

Several models were summarized and described by Grimsrud, et al.,[47] as a good sampling of the type of models recently available for use in stream water quality studies. The documentation corresponding to these models is, or soon will be, available to the public through government agencies. The models were separated into 3 types: (1) steady-state models in which the variables involved are unchanging with time, (2) dynamic-equilibrium models that vary with time but only in a cyclically repititious manner, and (3) dynamic models in which the inputs and outputs may vary freely with time. It was also noted that none of these models are applicable to frozen conditions. The following discussion briefly describes several of the models and model characteristics are summarized in Tables 11 and 12.

STEADY STATE MODELS

Three models were evaluated in this category: Simplified Stream Model, DOSAG-1 and SNOSCI.

The Simplified Stream Model was developed by Hydroscience, Inc., for the EPA Water Programs Office. Various tables, charts, nomographs, figures and technical data are incorporated into the model and may be used to analyze water quality and to estimate treatment levels needed to meet specific receiving water quality standards. Calculations with a slide rule or small calculator are intended to assist in interim planning only and complex river systems or water quality problems cannot be analyzed.

DOSAG-I is a computer program model prepared by the Texas Water Quality Board. The Streeter-Phelps oxygen sag equation is used to simulate BOD and DO variations. It is useful for rapid evaluation of a number of varying stream conditions. SNOSCI is a modification of DOSAG-I, prepared by Systems Control, Inc. The major modification is the added capability to simulate many more water quality parameters than just BOD and DO.

DYNAMIC EQUILIBRIUM MODELS

The models evaluated in this category are QUAL-I and QUAL-II. Both are computer programs.

TABLE 11

STREAM MODEL FEATURES, AQUISITION AND COSTS

Model	Time Domain	Failures or Limitations	Constituent Modeled		Internal Decay and/or Growth Processes	Model Acquisition	Equipment & Staff Requirements	Model Costs	
			Original Model	Possible with Minor Modification				Machine	Manpower
Simplified Stream	Steady State	Point sources only	Conservatives Coliform, BOD, Nutrients Coupled BOD-DO deficit	—	1st order decay, BOD-DO coupling, reaeration, temp effects	Handbook from EPA Planning Assistance Branch	Calculator, one junior level engineer with some experience in modeling	0	1-2 Manweeks
DOSAG-I	Steady State	Point and Distributed Non-point sources	DO, BOD (Carbonaceous and Nitrogenous)	—	1st order decay, BOD-DO coupling, reaeration, temp effects	Nominal cost from EPA Planning Assistance Branch, D.C.	Computer, FORTRAN IV Compiler, one engineer familiar with programming	$1 - $5	2-6 Manweeks
SNOSCI	Steady State	As above plus power plant option for excess temperature	DO, BOD, T. coli, F. coli, algae, NH_3, NO_2, NO_3, OPO_4, Cu, Pb, Temperature excess plus 4 conservatives	Any 4 conservatives and any 4 non-conservative with first order decay	1st and 2nd order decay, reaeration, linking of constituents Temp. effects, Benthal releases and demands	Nominal cost from Snohomish County Planning Dept., Wa., or SCI, Calif.	Computer, FORTRAN IV Compiler, one engineer familiar with programming	$2-$10	4-8 Manweeks
QUAL-I	Steady State (weather inputs can be dynamic)	Point Sources only	DO, BOD, Temp. and any three conservative constituents	—	BOD 1st order decay. BOD-DO coupling, reaeration temp.	Nominal cost from EPA Planning Assistance Branch, D.C.	Computer, FORTRAN IV Compiler, one engineer familiar with programming	$5-$50	2-6 Manweeks
QUAL-II	Steady State (weather inputs can be dynamic)	Point Sources only	DO, BOD, Temp. NH_3, NO_2, NO_3 algae, phosphorus, benthic demand, coliforms, radioactives, three conservative constituents	—	Numerous Algae-Nutrient interactions, BOD-DO coupling, 1st order decay, reaeration, temp. effects	Nominal cost from EPA Planning Assistance Branch, DC	Computer, FORTRAN IV Compiler, one engineer familiar with programming	slightly higher than above	4-10 Manweeks
RECEIV	Dynamic	Handles tidal flats, waste loads may be dynamic	Any 6 constituents including conservative constituents with 1st order decay	—	1st order decay, BOD-DO coupling, reaeration	EPA, Environmental Research Lab Corvalis, Oregon	Computer, FORTRAN IV Compiler, one engineer in modeling and one experienced programmer	Quantity $15-$100 Quality $10-$50	3-20 Manweeks
[illegible]	Dynamic	Handles tidal flats, waste loads may be dynamic	Excess temp., DO, BOD, T. coli, fecal coli, NH_3, NO_2, NO_3, OPO_4, Cu, Pb and two conservatives	Any 2 non-conservatives with 1st order decay, or 2 more conservatives, in place of Cu and Pb	Above plus 2nd order decay, nutrient algae cycle, and temp. effects	EPA, Environmental Research Lab Corvalis, Oregon	Computer, FORTRAN IV Compiler, one engineer in modeling and one experienced programmer	As above with increase cost as number of constituents increase	3-20 Manweeks

TABLE 12

STREAM MODEL DATA REQUIREMENTS

Model	DATA REQUIRED FOR MODEL INPUTS						Required for Model Calibration & Verification	Model Output
	Hydrologic	Hydrodynamic (Including Geometry)	Water Quality	Effluent	Decay Rates	Other		
Simplified Stream	Net river flow	Depths, velocities; distance from outfalls.	Constituent concentration (constant) at headwaters and tributaries; water temperature, plus background DO deficit	UOD loading rate, (may be obtained from charts)	Deoxygenation coefficients	—	Constituent concentrations within modeled area	DO deficit and DO concentrations
DOSAG-I	Headwater flows, tributary and discharge flows, withdrawal flows, groundwater flows (all constant)	Reach lengths	Constituent concentration (constant) at headwaters and tributaries; water temperature	Flow rates and constituent concentrations	Reaeration and two deoxygenation coefficients, temperature correction factors	Treatment factors	Stream flows, stream velocities and constituent concentrations within modeled area	Descriptive computer listing of: input data, DO, CBOD and NBOD at start and end of each reach, minimum DO and location in each reach
SNOSCI	Headwater flows, tributary and discharge flows, withdrawal flows, groundwater flows (all constant)	Reach lengths	Constituent concentration (constant) at headwaters and tributaries; water temperature	As above, plus cooling water temperature rise	Rate coefficients, temperature correction factors	Treatment factors	Stream flows, stream velocities and constituent concentrations within modeled area	Descriptive computer listing of: input data, DO, CBOD and NBOD at start and end of each reach, minimum DO and location in each reach
QUAL-I	Headwater flows, tributary flows, withdrawal flows, groundwater flows, (all constant)	Depths and widths, bottom roughness (Manning's n) all throughout stream	Constituent concentration (constant) at headwaters and tributaries	Constant flow and concentrations	BOD decay rates	Weather, lat-long of basin, day of year, evaporation coefficients	Stream flows, stream velocities and constituent concentrations within modeled area	Computer listing of constituent concentrations at specified timesteps, max., min., and ave. concentration for each reach
QUAL-II	Headwater flows, tributary flows, withdrawal flows, groundwater flows, (all constant)	Depths and widths, bottom roughness (Manning's n) all throughout stream	Constituent concentration (constant) at headwaters and tributaries	Constant flow and concentrations	Numerous parameter decay rates and settling coefficients	Weather, lat-long of basin, day of year, evaporation coefficients	Stream flows, stream velocities and constituent concentrations within modeled area	Computer listing of constituents at specified timesteps, final constituent concentrations and ave. reach coefficients used
RECEIV	Constant headwater flows; constant or dynamic tributary and effluent discharge flows; constant groundwater flows; seaward tides in estuary	Channel depths and widths, bottom roughness, initial velocities	Constant or dynamic constituent wasteloads from tributaries & headwaters, seaward exchange coefficients	Constant or dynamic constituent loads from effluents	First order decay rates or all nonconservative constituents	Windspeed & rain, for estuaries: seaward exchange coefficient	As above plus estuaries require salinity or dye data for calibration of seaward boundary inputs	Computer listing of max, min, and ave concentration at each junction at prescribed time intervals, summary of each tidal cycle including max, and min flows, velocities, heads, net flows and junction depths
SRMSCI	Constant headwater flows; constant or dynamic tributary and effluent discharge flows; constant groundwater flows; seaward tides in estuary	Channel depths and widths, bottom roughness, initial velocities	Constant or dynamic constituent wasteloads from tributaries & headwaters, seaward exchange coefficients	Constant or dynamic constituent loads from effluents	1st or 2nd decay rates or all non-conservative constituents .	Windspeed & rain, for estuaries : seaward exchange coefficient	As above plus estuaries require salinity or dye data for calibration of seaward boundary inputs	Computer listing of max, min, and ave concentration at each junction at prescribed time intervals, summary of each tidal cycle including max, and min flows, velocities, heads, net flows and junction depths

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QUAL-I was developed by W.A. While, and others in collaboration with the Texas Water Development Board. It is capable of simulating temporal and longitudinal variations of temperature, BOD, DO and conservative constituents in a one-dimensional, vertically well-mixed, branching river with multiple waste inputs, withdrawals and incremental runoff within the basin. Differential mass-transport equations form the basis for the model with terms for longitudinal advection and dispersion included. It is more accurate and provides a more precise definition of the stream conditions than DOSAG-I described above. The two programs can be used together. DOSAG-I can provide the user with a rapid evaluation of a number of alternative conditions while QUAL-I gives a more detailed analysis of the physical phenomena of the stream.

QUAL-II, prepared by Water Resources Engineers, is a modification of QUAL-I that principally adds the capability to simulate eight more water quality constituents.

DYNAMIC MODELS

The two models reviewed in this category are RECEIV and SRMSCI.

RECEIV is the name of the receiving water module of the Storm Water Management Model developed by Metcalf and Eddy, Water Resources Engineers, and the University of Floride. RECEIV was developed, principally by WRE, by incorporating into a previous dynamic equilibrium model the capability to simulate the transient behavior (toward a dynamic equilibrium) and associated problems cased by dunamic storm water inflows. This model can also simulate estuaries including a tidal cycle at the seaward boundary.

SRMSCI is a modification of RECEIV, prepared by Systems Control, Inc., and first applied to the Snohomish and Stillaguamish River estuaries of Washington. The principal modification was the added capability to simulate many more water quality constituents.

Both of these models accept transient inputs, such as dynamic (non-steady and non-cyclic) storm water inflow (quantity and quality), resulting in a dynamic transient solution which tends back to the pre-storm dynamic equilibrium.

OTHER MODELS

There are many models that are not described herein nor summarized in Tables 11 and 12. Most of the models not discussed herein are intended for very specific situations. For example, the Hydrocomp Simulation Model, available from Hydrocomp International, Palo Alto, California, models temperature, BOD coliforms, algae, zooplankton, sediment, organic nitrogen, DO, TDS, nutrients and conservative constituents. It is particularly useful for its capability to preduct water runoff and the resulting stream quality as a function of varying weather conditions. RECEIV-II, available from EPA, Planning Assistance Branch, Washington, D.C., includes multiple tidal inlets, upstream dams and storm water flows.

A major consideration in the use of any model is the type, amount and accuracy of data needed to carry out meaningful computations. It should be noted that all of these models contain constants that deal with dispersion, sorption, reaeration and diffusion rates. The values of these constants should be obtained through experimental work for the river basin being modeled.

The report by Grimsrud, et al.,[47] is specifically designed as a handbook for water resource planners and managers and is an excellent guide for evaluation, selection and integration of modeling with planning activities. This report, "Evaluation of Water Quality Models, A Management Guide for Planners", is available from the U.S. Department of Commerce, NTIS PB-256 412, July 1976.

SECTION 5

CAPABILITY OF TREATMENT PROCESSES FOR CONTAMINANT REMOVAL

GENERAL

Many of the contaminants in the Primary and Secondary Drinking Water Regulations are removed by conventional water and wastewater treatment processes. It is possible with existing treatment technology to remove any contaminant and produce virtually any desired level of effluent quality. In general, the costs and complexity of treatment systems are greater to reduce contaminants to very low concentration levels.

The following terms are used in this report to describe treatment systems.

- Conventional Wastewater Treatment. Primary and biological secondary treatment plus chlorination. Biological secondary processes commonly used are activated sludge, trickling filter and oxidation pond.
- Advanced Wastewater Treatment (AWT). AWT is a broad term that implies treatment in addition to conventional secondary wastewater treatment. AWT may involve one or several treatment steps such as chemical clarification (coagulation, flocculation and sedimentation), filtration, activated carbon adsorption, nitrogen removal and other processes.
- Conventional Water Treatment. Chemical clarification, filtration and disinfection.
- Upgraded Water Treatment. Chemical clarification, mixed media filtration, with turbidity monitoring and polymer feed systems, carbon adsorption and disinfection.
- Physical-Chemical Processes. These processes are similar for water or wastewater treatment and include: chemical clarification, filtration, chlorination, activated carbon adsorption, reverse osmosis, and ion exchange. The design of the units, unit loadings and chemical dosages may vary between water and wastewater treatment systems, but the basic process and removal mechanisms are similar.

The contaminants of concern in the primary and secondary drinking water regulations are divided into the following general categories:

Microbiological contaminants (coliform bacteria)
Turbidity
Organic chemicals
Inorganic chemicals
Radioactive material

Public Law 93-523 provided for the establishment of the Primary Drinking Water Regulations and also stated that EPA should identify treatment technology that could be used to achieve the maximum contaminant levels (MCL). Accordingly, in May, 1977 EPA published a report entitled "Manual of Treatment Techniques for Meeting the Interim Primary Drinking Water Regulations".[48] This manual is based on a literature review and research conducted by the Water Supply Research Division of EPA. The EPA water treatment data are summarized herein and supplemented with other appropriate information.

MICROBIOLOGICAL CONTAMINANTS

Coliform bacteria are an indicator of pollution because they are always present in the intestinal tract of humans and warm blooded animals and are eliminated in large numbers in fecal wastes. The detection of disease causing bacteria, virus and other pathogenic organisms is much more difficult and time consuming than are tests for coliforms. However, several studies have indicated that some pathogenic organisms survive longer than coliforms in water, and are not as efficiently removed by treatment, including chlorination.

Water and wastewater can be disinfected with chlorine, chlorine dioxide and ozone. Chlorine dioxide and ozone are powerful disinfectants but have not been used to any extent in the United States because they cannot be transported and must be generated at the treatment plant site. In addition, there is little scientific knowledge currently available regarding the health effects of by-products of these disinfectants. Chlorine is by far the most widely used disinfectant in the United States. However, studies in recent years have revealed that chlorination creates organic by-products that may be hazardous to human health. One method of minimizing the chlorine-organic by-products is to chlorinate at the point in the treatment process with the best quality water.

Disinfection efficiency increases with water clarity. Treatment processes that remove suspended material usually remove some bacteria and virus and greatly increase the efficiency of downstream disinfection. Turbidity in the disinfection process should be below 1 TU and preferably below 0.1 TU.[49]

In addition to water turbidity, other factors influencing disinfection with chlorine include chlorine form (free or combined), water temperature and pH. Other factors being equal, chlorination efficiency is directly related to chlorine concentration and contact time.

Conventional wastewater treatment processes coupled with chlorination provide substantial reductions but not complete removal of bacteria and virus. Primary and secondary treatment processes may provide bacteria and virus reduction of about 90 percent and also enhance the efficiency of downstream disinfection processes by removing solids and other materials which would interfere with disinfection. With efficient secondary treatment and maintenance of adequate chlorine residual and contact time, reduction of over 99 percent of virus and bacteria have been achieved. However, in most normal operating facilities expected coliform levels are 10^6 - 10^7 per 100 ml and viruses are on the order of 100 per gallon.

AWT processes also provide significant reductions in virus and bacteria as well as improving the efficiency of disinfectants by further removal of solids and other interfering substances. Chemical clarification (and also filtration is some cases) has been found by several researchers[49-59] to provide high degrees of removal of viruses. Alum clarification was found to remove 95 to 99 percent of coxsackie virus and ferric chloride clarification was found to remove 92 to 94 percent of the same virus.[50] Good virus removal with both alum and ferric chloride, was contingent upon good floc formation and the absence of interfering substances. The presence of organic material was shown to decrease the amount of virus removed by alum or ferric chloride.

In one study it was observed that polio virus Type I was removed by flocculation and filtration with about the same efficiency as coliforms.[51] If a low but well mixed dose of alum was fed just ahead of the filters and operated in the range of 2 to 6 gallons per minute per square foot, more than 98 percent of the viruses were removed by 16 inches of coarse coal on top of 8 inches of sand. If the alum dose was increased and conventional flocculators and settling were used, the removal was increased to over 99 percent. Large scale pilot studies at Dallas, Texas[52] demonstrated removals of bacterial virus of over 99 percent for chemical clarification and over 99.9 percent for chemical clarification with alum followed by filtration.

Lime clarification has demonstrated the ability to effectively remove and inactivate virus at high pH values. The mechanism of inactivation under alkaline conditions is probably caused by denaturation of the protein coat and disruption of the virus. In some cases complete loss of structural integrity of the virus may occur under high pH conditions. The pH reached in lime treatment is a critical factor in determining the degree of virus inactivation with marked increases in virus inactivation as the pH is increased from 10.1 to 10.8 and then to 11.1.[53]

The pilot plant at Dallas, Texas[52] also found that only a few gram positive rods could survive high pH lime treatment (pH of 11.2 to 11.3 with contact times of 1.6 to 2.4 hours). The virucidal effect of the pH treatment is reflected by the fact that no viable polio virus were recovered from the sludge resulting from the high pH treatment.

The AWWA Committee report on virus in water[49] concluded that "... *in the prechlorination of raw water, any enteric virus so far studied would be destroyed by a free chlorine residual of about 1.0 ppm, provided this concentration could be maintained for about 30 minutes and that the virus was not embeded in particulate material. In postchlorination practices where relatively low chlorine residuals are usually maintained, and, in water about 20°C and pH values not more than 8.0-8.5, a free chlorine residual of 0.2-0.3 ppm would probably destroy in 30 minutes most viruses so far examined.*"

In general, ozone has been found to equal or exceed chlorine in its germicidal effects under a wide variety of circumstances.[60] Measurements of the virus kill in secondary effluent found that seeded coliphage F_2 was totally destroyed in five minutes in secondary effluent by 15 mg/l of ozone.[61] Another study found that only 0.006 percent of polio virus in secondary effluent survived one minute of contact with an initial ozone concentration of 5 mg/l.[62] It was found that a threshold value for initial ozone concentration of about 1 mg/l had to be surpassed before extremely high (greater than 99.9 percent) virus kills resulted.

The overall pathogen removal capability of primary and secondary treatment followed by chemical clarification, mixed media filtration, granular activated carbon adsorption, and chlorination is reflected by the data from two full scale wastewater reclamation plants.

1. South Lake Tahoe, California, 7.5 mgd AWT plant following activated sludge secondary treatment. Of 1,731 final effluent samples examined from 1972-1976, 1,677 (97 percent) had coliform concentrations of less than 2.2/100 ml and only 2 samples exceeded 38/100 ml. Although virus tests were limited, no viruses were detected in the final effluent.
2. Orange County California, 15 mgd AWT plant following trickling filter secondary treatment. Chemical clarification with lime and polymer raises the pH to about 11.2. Viruses in the secondary effluent average 100 plaque forming units per gallon and are reduced to an average of 2 plaque forming units per gallon by lime clarification. No viruses or bacteria were detected in the final AWT plant effluent after more than one year of operation. Treatment after chemical clarification includes ammonia stripping, recarbonation, mixed media filtration, granular activated carbon adsorption and chlorination.

TURBIDITY

The MCL for turbidity is 1 TU in most circumstances. Primary wastewater treatment commonly removes 60 to 65 percent of the influent suspended solids. A well operated secondary wastewater treatment plant can produce effluent with a turbidity of 10 to 30 TU. Chemical clarification of secondary effluent can reduce turbidity to a range of 1 to 5 TU. Filtration of chemically clarified water or wastewater with filter aids (polymer and alum) can produce effluent with turbidity of 0.1 to 1 TU. Direct filtration of secondary effluent (without chemical clarification) is capable of reducing turbidity to 1 to 5 TU, depending upon the degree of flocculation achieved in the secondary biological process.

ORGANIC CHEMICALS

The Primary Drinking Water Regulations established MCL's for six organic chemicals: endrin, lindane, methoxychlor, and toxaphene - which are chlorinated hydrocarbons - and two chlorophenoxys, 2,4-D and 2,4,5-TP (Silvex). These six specific organic contaminants can be grouped under the general term "pesticides". It is proposed by EPA to add to the Primary Regulations a MCL of 0.10 mg/l for total trihalomethanes. It is also proposed by EPA to specify MCL's for additional organic compounds. Raw water supplies that are vulnerable to significant contamination with synthetic organic chemicals will be required to provide granular activated carbon, or equivalent, treatment. The Secondary Drinking Water Regulations established MCL's for three contaminants that are most often caused by organic chemicals: foaming agents, color and odor.

In addition to the specific organic compounds in the Drinking Water Regulations, organics are of concern that are (1) not removed by primary secondary and advanced wastewater treatment, and (2) not removed by conventional water treatment. Regarding organics in drinking water, the National Academy of Sciences study[1] states:

> *"The organic compounds that have been identified in drinking water make up a small fraction of the total organic matter present. About 90 percent of the volatile organic compounds have been identified and quantified, but these represent no more than 10 percent by weight of the total organic material. Only 5 - 10 percent of the non-volatile organic compounds, that comprise the remaining 90 percent of the total organic material, has been identified. (In this context, volatile signifies that the compound is detectable by gas chromotography.)"*

Organic compounds studied by the National Academy of Sciences were selected according to the following criteria.

> *"The compounds selected for the review in this study included 74 non-pesticides of the approximately 309 volatile organic compounds so far identified in drinking water, and 55 pesticides. Some of the pesticides studied have not yet been detected in drinking water, but were included because they are or have been used in large quantities. A compound was selected for consideration if any of the following criteria applied:*
>
> 1. *Experimental evidence of toxicity in man or animals, including carcinogenicity, mutagenicity, teratogenicity.*
> 2. *Identified in drinking water at relatively high concentration.*
> 3. *Molecular structure closely related to that of another compound of known toxicity.*
> 4. *Pesticide in heavy use; potential contaminant of drinking water supplies.*
> 5. *Listed in the National Interim Primary Drinking Water Regulations."*

Studies by EPA have shown that chloroform is the principal trihalomethane present in municipal finished water supplies.[63] Bromodichloromethane, dibromochloromethane and tribromomethane were also frequently found and dichloroiodomethane was detected in some finished waters. The Secondary Drinking Water Regulations contain limits for three contaminants (foaming agents, color and odor) that are most often caused by organic chemicals.

Because the analysis for chloroform is a gas chromatographic procedure requiring skilled operators and about one hour to complete, EPA conducted studies in search for a surrogate or substitute measurement that would predict chloroform concentrations.[63] Three general organic tests were studied as substitute parameters: (1) non-purgeable total organic carbon, (2) ultraviolet absorbance and (3) emission fluorescence scan. The correlation between these potential substitute parameters and chloroform was not consistent and it was concluded that the best method of determining the chloroform concentration is to obtain the necessary equipment and technical staff to perform the analysis directly. Special equipment and skilled operators are also required to make the substitute measurements and therefore, little can be gained by their use.

There are three basic ways of controlling trihalomethanes in drinking water:

1. Use of a disinfectant that does not generate trihalomethanes in water.
2. Treatment to reduce the precursor concentration prior to chlorination.
3. Treatment to reduce the trihalomethane concentration after formation.

Each of these general approaches can be further divided into other control options, depending upon individual circumstances. However, these should not be considered as distinct options. Indeed, in many cases some combination of all three may be necessary to simultaneously minimize organic and optimize pathogen control.

Since any of the disinfectants or their corresponding by-products may have some undesirable properties, a fundamental principle should be to apply whatever treatment is needed to produce water of high quality and low chemical content prior to the application of the disinfectant. Thus the chemical disinfectant demand of the water will be minimized and disinfection will be maintained while disinfectant use and by-product formation will be minimized.

Measures of Organic Pollution

The current state of water analysis technology requires that the presence of trihalomethanes and the six pesticides contained in the Primary Drinking Water Regulations be determined by direct measurement. Although measurement of the organic contaminants in the Primary Drinking Water Regulations must be made directly, there is much interest in measuring the general organic quality of raw and finished water. The pesticides and trihalomethanes included in the Primary Drinking Water Regulations will represent only a small fraction of the organic material present in most waters; therefore, some other parameter must be used to monitor the remaining organics. Determination of foaming agents, color and odor included in the Secondary Drinking Water Regulations may also be monitored by measurement of a more general organic parameter.

There are three general measures of organic pollutants that are used tc varying degrees at the present time: biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total organic carbon (TOC). Most wastewater treatment studies and operating plants do not test for specific organic constituents but rather monitor organics by measuring BOD, COD or TOC. Measurements of gross organic concentrations have limitations. For example, the COD procedure fails to detect many straight-chain aliphatic and aromatic hydrocarbons, and pyridine. However, these measurements do give an indication of the total amount of organics present and make up the bulk of the available data.

BOD - This parameter has been used over the longest period of time to measure organic pollution and is included in the EPA definition of secondary treatment. The BOD test measure the amount of oxygen consumed by bacteria and other organisms during the stabilization of organic wastes. The standard test requires five days to complete.

COD - This parameter was developed as a substitute or supplement to the BOD analysis. Whereas the BOD test relies on biological activity to oxidize organic matter, the COD analysis utilizes a powerful chemical oxidizing agent. One advantage of the COD test is that it can be performed in about two hours as opposed to a minimum of five days for the BOD test.

TOC - This test was developed relatively recently and requires more expensive equipment and skilled operation than either BOD or COD. TOC is measured with an instrument that converts all carbon in the sample to carbon dioxide and the carbon dioxide is then measured by an infrared analyzer. No organic chemicals have been found that will resist oxidation in the analyzer. The TOC analysis can be performed in about five minutes or less.

Some organic compounds are biologically oxidized but resist chemical oxidation; other organics are oxidized chemically but not biologically; and there are no known organic compounds that will resist the catalytic oxidation in the TOC analyzer. Because of the vastly different methods of oxidizing organic material, there is no inherant correlation between the three different methods of analysis. However, it is sometimes possible in specific locations to establish an empirical relationship between BOD or COD and TOC. Eckenfelder notes that the BOD/COD ratio of wastewater changes through treatment and gives a ratio of 0.5 to 0.7 for raw biodegradable wastewaters and 0.03 to 0.2 for biologically treated effluents.[64]

There have been several studies that attempted to correlate the instrumental TOC results with the more traditional parameters of BOD and COD. In many wastewaters, a reliable correlation has been found and, in general, these are wastes that are fairly consistent in composition. Municipal wastewaters and industrial wastes that contain the same relative constituents but variable concentrations have shown a consistent correlation between BOD and TOC. Data from three studies[65-67] gives the following correlations between BOD, COD and TOC.

Relationship	Water Type
BOD/TOC 1.35 to 2.62	Raw domestic sewage
BOD/TOC 1.31 to 1.63; mean = 1.46	Raw domestic sewage
BOD/TOC 1.00 to 1.33; mean = 1.11	Primary effluent
BOD/TOC 0.31 to 0.61; mean = 0.46	Secondary effluent
COD/TOC mean = 2.92; standard deviation = 0.292	City of Midland, Michigan Primary effluent
COD/TOC mean = 2.76; standard deviation = 0.275	City of Midland, Michigan Secondary effluent

One study measured BOD, COD and TOC for various stream waters and wastewaters and concluded that:[68]

1. *There is a significant correlation between BOD and TOC for domestic wastewater samples which have been collected from a specific location within a treatment process.*
2. *For a treated domestic wastewater secondary effluent, the BOD to TOC correlation was stronger than the COD to TOC relationship.*
3. *While major variation in BOD and TOC concentrations were observed in the river study portion of this investigation, the correlation between BOD and TOC was significant at the 0.01 level when all river samples were considered.*
4. *A sharp decrease in BOD to TOC correlation was evident as the river approached higher flow conditions.*

The report on this study[68] notes that the expected stoichiometric COD:TOC ratio of wastewater will approximate the molecular ratio of oxygen to carbon of 2.67. However, this ratio can range from below 2.67 for organics resistant to chemical oxidation to over 2.67 for some organic compounds or when inorganic reducing agents are present. The estimated relationship between 5-day BOD and TOC for domestic wastes is as follows:

$$\frac{BOD_5}{TOC} = \frac{32}{12} \quad (0.90)\ (0.88) = 1.85$$

where the ultimate BOD exerts 90 percent of the theoretical oxygen demand and the 5-day BOD is 77 percent of the ultimate BOD. Actual BOD and TOC data from the study[68] are summarized as follows:

Source	BOD, mg/l	TOC, mg/l	BOD/TOC
Raw sewage (7 samples)	56 to 450	76 to 175	0.67 to 2.53
Secondary Effluent (7 samples)	2 to 40	9 to 51	0.22 to 0.78
River water (9 samples)	4 to 9	2 to 24	0.29 to 0.56

The results indicated that the river flow had a pronounced effect on the BOD:TOC relationship. The BOD:TOC correlation was much better at low flow than high flow conditions.

Activated carbon is the most effective and widely used treatment method for removal of dissolved organic material from water and wastewater. Reverse osmosis and ion exchange are also effective for the removal of many organic compounds. Chemical clarification and oxidation with chlorine ozone or potassium permanganate have also been effective for removal of some organics in some waters. The EPA report on water treatment techniques[48] discusses methods of removing the six pesticides in the Primary Drinking Water Regulations and concludes that carbon adsorption is more effective than conventional treatment or oxidation for pesticide removal.

Activated Carbon

Adsorption of specific organic compounds from municipal wastewaters is a complex problem. Even if data are available on the adsorption of a specific organic from a pure solution, the data are of limited value in predicting the removal of this compound from the heterogenous mixture of organics found in municipal wastewaters. Two different materials may enhance the adsorption of one another or they may interfere. One study found that the capacity of carbon is enhanced in the presence of several compounds as compared to that obtained in single-solute solutions.[69]

The literature contains information on removal of specific organic compounds,[70-76] but unfortunately these studies have been made with single solutes or mixtures of solutes in pure water rather than in municipal wastewaters. These studies do indicate that molecules having highly branched structures are removed much more slowly than those of identical molecular weight but with configurations that permit coiling and compactness which result in high rates of diffusion into the pores of the carbon.

The ability of carbon to remove organics from water has been reported in several articles,[77-84] and a report published in August, 1977 reviews the state of the art of granular activated carbon in water treatment.[85]

An activated carbon column providing 14 minutes contact time reduced 6.3 μg/l of endrin in lake water to 0.006 - 0.085 μg/l.[77] Dieldrin (3.5 mg/l) and lindane (8 mg/l) have been reported to be removed by powdered carbon dosages of 35 to 40 mg/l.[78] Table 13 presents data collected in isotherm tests on aldrin, dieldrin, endrin, DDD DDE, DDT, toxaphene, and Arochlor 1242 and 1254.[76] The first seven are pesticides and the last two are mixtures of PCB's containing 42 percent and 54 percent chlorine by weight. The isotherm data were collected on solutions of the material added to distilled water. This data illustrates the capability of activated carbon for removal of these contaminants.

Removals of chloroform and bromodichloromethane, formed by chlorination of wastewater, in carbon columns providing only 2.5 minutes of contact time have been reported.[28] Influent chloroform concentrations were 11 to 96 mg/l and bromodichloromethane concentrations were 0.1 to 19 mg/l. Chloroform was reduced to less than 1 μg/l during the first day's operation and increased in concentration until complete breakthrough occured on the eighth day. Carbon effectively reduced bromodichloromethane to nondetectable concentrations except for the eighth day when a single value of 0.3 μg/l was observed. All other compounds were absent in the carbon effluent. Carbon capacity for chloroform was determined to be 0.073 mg chloroform per gram carbon with 2.5 minutes contact time.

The removal of organics by activated carbon treatment of secondary municipal wastewater effluents is affected by many variables such as the degree of pretreatment, the contact time in the carbon column, the frequency with which carbon is removed for regeneration, and the nature of the organics present. One of the early studies on carbon treatment[73] found that provision of chemical clarification and filtration prior to adsorption provided a marked improvement in activated carbon effluent COD over that obtained with activated carbon treatment of secondary effluent. On the same wastewater, isotherms showed that COD values of 5 mg/l were achievable with chemically clarified and filtered secondary effluent while 20 mg/l was the best achieved

TABLE 13

REMOVAL OF TOXIC MATERIALS BY CARBON ADSORPTION

(after Hager and Rizzo[76])

Carbon Dosage (mg/1)	Residual, μg/l								
	Aldrin	Endrin	Dieldrin	DDT	DDD	DDE	Toxa-phene	Arochlor 1242	Arochlor 1254
Control........	48	62	19	41	56	38	155	45	49
1.0............	-	-	-	41	-	34	147	-	-
2.0............	26	15	6.3	-	6.9	-	80	7.3	37
2.5............	-	.	.	21	.	29	-	-	-
5.0............	15	3.4	2.4	3.7	3.7	12	31	1.6	17
10.0...........	12	1.5	1.1	-	2.2	-	2.7	1.1	4.2
12.5...........	-	-	-	<1	-	3.3	-	-	-
25.0...........	6.3	0.56	-	-	0.45	1.1	-	-	1.6
50.0...........	4.4	0.22	-	-	0.35	0.9	-	-	1.2

with secondary effluent with no pretreatment. Pilot column tests at several locations showed that effluent TOC values with chemical clarification and filtration as pretreatment were 0.1 mg/l, while with filtration as the only pretreatment, TOC values were 2 to 5 mg/l.[86]

The Pomona pilot plant has achieved COD values of less than 10 mg/l by carbon treatment of secondary effluent with no pretreatment.[87] The review of granular activated carbon use for water treatment also noted the effect of pretreatment on activated carbon treatment efficiency and concluded that the use of granular activated carbon for reduction of TOC should be preceded by good clarification because many organics are removed by this step.[85] Chemical clarification and filtration will remove many color causing humic substances. Some trace organics such as pesticides may be associated with silt and particulate humic substances.

Middleton[88] states that COD values can be reduced to less than 3 mg/l with carbon treatment of a well-treated secondary effluent and that a TOC of less than 1 mg/l can be achieved at contact times of 15 minutes or more. Middleton also reports achieving TOC values of 1.2 mg/l with powdered carbon treatment at Lebanon, Ohio.

COD values of less than 3 mg/l have been produced in pilot tests and in the full-scale plant at Lake Tahoe.[89] The Orange County, California full-scale plant achieved an average COD of 15 mg/l (with a standard deviation of 6 mg/l) over the period of February, 1976 to March, 1977.[90] Minimum values of 4 mg/l were achieved during this period. Data on organic removals in full-scale AWT plants in Colorado Springs, Colorado, South Lake Tahoe and Orange County, California, are summarized in Table 14.

Although the data indicates that there may only be 2 to 3 mg/l of COD that is typically resistant to carbon adsorption, it is often impractical to continuously produce such a value. For example, analysis of the South Tahoe data from January-November, 1974 indicates that only 7 percent of the measured COD values were less than 5 mg/l with 66 percent being less than 15 mg/l. In previous years, the COD has typically been 10 mg/l or less for 80 percent of the time with 20 percent of the values being between 10 and 22 mg/l.

One of the reasons that effluent COD values show variability is that it is not practical to maintain carbon contactors continuously full of freshly regenerated carbon. Minimum values of COD (3 mg/l) are typically achieved with a column filled largely with fresh carbon. As the carbon becomes saturated, the effluent COD increases. When some of the spent carbon is replaced with regenerated carbon, the COD value drops. It appears that COD values of 10 to 12 mg/l are practical goals for full-scale AWT plants for activated carbon effluent. Unfortunately, there are few data on the specific organic compounds which are likely to comprise the 10 to 12 mg/l COD escaping an efficient carbon adsorption system.

One study reported that the major organic fraction adsorbed in activated carbon columns is a fulvic acid-like material with a molecular weight fraction ranging from approximately 100 to 10,000.[91] Both the low molecular weight fraction consisting of mostly polar organic compounds and the high molecular weight humic carbohydrate-like material, with a molecular weight above 50,000 were poorly adsorbed. The total COD passing the carbon column in these tests was 6 mg/l.

TABLE 14

TYPICAL QUALITY OF ADVANCED WASTEWATER TREATMENT PLANT PRODUCT WATER

(mg/l except as noted)

PARAMETERS	DRINKING WATER MCL	FULL SCALE AWT PLANT		
		South Tahoe California	Orange County California	Colorado Springs Colorado
Primary Regulations				
Arsenic	0.05	0.005	0.001	0.003
Barium	1	--	0.03	--
Cadmium	0.010	--	0.002	0.000
Chromium	0.05	0.0005	0.05	0.022
Fluoride	1.4 to 2.4^1		1.2	
Lead	0.05	--	0.02	0.07
Mercury	0.002	--	0.0005	0.0
Nitrate (as N)	10		<1	
Selenium	0.01	0.0005	0.007	--
Silver	0.05	0.0004	0.001	--
Endrin	0.0002	--	<0.0001	--
Lindane	0.004	--	<0.0001	--
Methoxychlor	0.1	--	<0.0001	--
Toxaphene	0.005	--	--	--
2, 4-D	0.1	--	--	--
2, 4, 5-TP Silvex	0.01	--	--	--
Turbidity	1^2	0.5	0.4	0.8
Coliform Bacteria	1^3	ND	ND	--
Secondary Regulations				
Copper	1	0.01	0.02	0.02
Iron	0.3	0.0003	0.14	0.012
Manganese	0.05	0.002	0.004	0.020
Zinc	5	0.005	0.13	0.12
Color, units	15		<1	2
Foaming Agents (as MBAS)	0.5		0.05	0.1
Odor, TON	3		<1	3
Other				
Trihalomethane	0.10^4	--	0.02	--
COD	None	20	20	15
TOC	None	--	8	10

[1] Varies with average annual maximum daily air temperature

[2] Monthly average

[3] Monthly average, membrane filter technique

[4] Proposed MCL

ND = None Detected.

Analyses of carbon column effluent from the full scale AWT plant in Orange County found chloroform concentrations of 0.7 to 4.5 μg/l, much less than the 10 to 300 μg/l found in drinking waters.[15] Concentrations of endrin, lindane and methoxychlor were less than 0.1 μg/l. The haloforms 1, 2 dichlorethane, carbon tetrachloride, bromodichloromethane, dibromochloromethane, and tribromomethane, if present, were found in very low concentrations (0.1 to 5 μg/l).

Reverse Osmosis

Reverse osmosis (RO) is best known for its use in the removal of inorganic chemicals - desalting or demineralization; however, RO is effective for the removal of many organics present in water and wastewater. RO removes some refractory and toxic organics of intermediate size and almost all high molecular weight (greater than 2,000) organics are removed very effectively.[92] Removal of low to intermediate molecular weight organics by RO is not always effective but in many cases partial removal is achieved. Another study[93] notes that: (1) RO removals increase with increasing molecular weight and, at constant molecular weight, with increasing branching, and (2) in the absence of experimental data, removal of organic compounds with molecular weights of less than 100 should not be assumed.

RO reduced the COD of secondary effluents from 39 mg/l to less than 1 mg/l at Pomona. The COD of activated carbon effluent was reduced from 11.4 mg/l to 0.3-1.0 mg/l. Activated carbon effluent at Hemet, California was reduced from 7.6 mg/l to 0.5-0.8 mg/l by RO. With chemical clarification and filtration as pretreatment of the secondary effluent, the Hemet unit reduced the COD from 35.2 mg/l to 1.5 - 3.4 mg/l.

A five mgd RO plant began operation in Orange County, California in July 1977 but water quality data are not yet available. The RO plant will receive secondary effluent treated by lime clarification, ammonia stripping, recarbonation, mixed media filtration and granular carbon adsorption. In RO pilot tests at Orange County, COD was reduced from 25 mg/l to 1.2 mg/l; however, the low molecular weight, relatively volative haloforms and other chlorinated organics were not removed.[90]

There are several RO plants in the United States that desalt ground water used for municipal water supplies. However, the largest RO plant operating in this country is used to treat wastewater in Orange County, California. The disadvantages of RO are its relatively high initial and operating costs. RO costs are covered in a following section on treatment costs.

RO produces a very high quality product water and when considering the total water resource system it would appear to be more appropriate to utilize RO in most situations as a water treatment process rather than an AWT process. The use of RO for water treatment is generally a more reliable less costly system that would make more direct use of the product water.

Ion Exchange

There has been some effort in recent years by ion exchange resin manufacturers to develop resins that will adsorb organics from water. The process has the potential to remove organics that are not removed by activated carbon or reverse osmosis.

A laboratory study at the University of Minnesota evaluated the ability of several anion exchange resins to adsorb organics from filtered Mississippi River water.[10] It was found that strongly basic anion exchange resins in column reactors could remove organics to below the 0.5 mg/l level detectable by the TOC analyzer. The resins could be easily regenerated with sodium chloride.

Ion exchange for removal of organics has not been used in a full scale water or wastewater treatment plant. The efficiency and costs must be demonstrated before this process can be considered an alternative to activated carbon or reverse osmosis.

INORGANIC CHEMICALS

A summary of the best treatment methods for removal of 9 of the 10 inorganic chemicals (excluding fluoride) in the Primary Drinking Water Regulations is presented in the EPA report on water treatment methods[48] and is shown in Table 15. This data indicates that chemical clarification, with iron salts, alum or lime is the most generally applicable method for removal of inorganic chemicals. Chemical clarification can be used for treatment of either water or secondary effluent.

Results of a study on raw and treated water at 12 plants in California and Colorado were reported by Zemansky[94] and data on six metals, chromium, copper, iron, lead, manganese, and zinc are summarized in Table 16. Concentrations of metals in the raw waters are higher than might be expected because supplies known to be contaminanted with industrial discharges were purposely selected for the study. However, cadmium and silver were below detectable concentrations at the 12 plants studied.

Chemical clarification of secondary effluent provides significant reduction of most heavy metals. Many of the trace metals form insoluble hydroxides at pH 11; therefore, lime clarification results in a reduction of these metal concentrations. It appears possible to reduce some of the metal concentrations below that predicted by the solubility products. This may be due to adsorption of the metal ions by the chemical floc. On the other hand, when any of the metals exist in organic form, the concentration reduction during lime clarification may be less than expected from solubility calculations. Table 17 summarizes data from several sources on metal removal from wastewater by lime clarification. Some of these data were collected on industrial metal wastes which have metal concentrations much higher than occur in domestic wastewater. Clarification with alum or iron salts also will remove some metals as shown in the data summarized in Table 18.

There have been several studies in recent years on the use of activated carbon to remove inorganic chemicals from water. Smith[97] and Sigworth and Smith [98] report that arsenic, chromium, copper, mercury, and silver may be significantly removed by adsorption on activated carbon. Lead and iron in the oxidized state also may be adsorbed to some extent by activated carbon. The removal of mercury by powdered activated carbon has been investigated in several studies; the work by Thiem and others[99] is summarized in the EPA report.[48]

A pilot plant treatment study on trickling filter effluent achieved good removals of silver, cadmium, chromium and selenium on 14 x 40 mesh granular activated carbon.[100] The data from this study are summarized as follows:

TABLE 15

MOST EFFECTIVE METHODS FOR REMOVAL OF INORGANIC CHEMICALS IN PRIMARY DRINKING WATER REGULATIONS

(from information in Reference 48)

Contaminant	Most Effective Methods
Arsenic $+^{3}$	Chemical Clarification (Oxidation Prior to Treatment Required) Ferric Sulfate, pH 6-8 Alum, pH 6-7 Lime
Arsenic $+^{5}$	Chemical Clarification Ferric Sulfate Coagulation, pH 6-8 Alum Coagulation, pH 6-7 Lime
Barium	Lime Clarification, pH 10-11 Ion Exchange
Cadmium	Ferric Sulfate Clarification, Above pH 8 Lime Clarification
Chromium $+^{3}$	Chemical Clarification Ferric Sulfate, pH 6-9 Alum, pH 7-9 Lime
Chromium $+^{6}$	Ferrous Sulfate Clarification, pH 7-9.5
Lead	Chemical Clarification Ferric Sulfate, pH 6-9 Alum, pH 6-9 Lime
Mercury, Inorganic	Ferric Sulfate Clarification, pH 7-8
Mercury, Organic	Granular Activated Carbon
Nitrate	Ion Exchange
Selenium $+^{4}$	Ferrous Sulfate Clarification, pH 6-7 Ion Exchange Reverse Osmosis
Selenium $+^{6}$	Ion Exchange Reverse Osmosis
Silver	Chemical Clarification Ferric Sulfate, pH 6-9 Alum, pH 6-8 Lime

TABLE 16

TRACE METAL OCCURRANCE AND REMOVAL OF TWELVE WATER TREATMENT PLANTS IN COLORADO AND CALIFORNIA

(after Zemansky[94])

Raw Water Concentration, mg/l			Average Percent Removals				Average Effluent
Metal	Average	High	Microstrainer*	Clarifier	Filter	Plant	Concentration, mg/l
Chromium	0.022	0.084	25	35	15	31	0.015
Copper	0.030	0.160	14	26	37	49	0.015
Iron	0.381	1.704	47	51	49	65	0.13
Lead	0.012	0.042	3	27	29	32	0.008
Manganese	0.128	0.963	36	30	55	65	0.045
Zinc	0.078	0.538	30	36	37	48	0.041

* Only four of the 12 plants equipped with microstrainers

TABLE 17

REMOVAL OF HEAVY METALS BY LIME CLARIFICATION

Metal	Concentration Before Treatment, mg/l	Concentration After Treatment, mg/l	Final pH	Percent Removal
Arsenic	23	23	9.5	0
	5	1.05	10.0	79(1)
	5	1.35	11.5	73
Barium	5	0.03	10	99(1)
	5	0.94	11.5	80
Cadmium	Trace	-	11	abt 50
	0.0137	0.0075	>11	94.5
	-	0.10	10	-
Chromium (+6)	0.56	0.50	>11	11
Chromium (+3)	7,400	2.7	8.7	99.9+
	15	0.4	9.5	97
Lead	15	0.5	9.5	97
	5	0.017	11.5	99.9+
Selenium	0.0123	0.0103	>11	16.2
Silver	0.546	0.0164	>11	97
	91	0.4	11	99.6
	91	12	10	87
Copper	15,700	0.79	8.7	99.9+
	7	1	8	86
	7	0.05	9.5	93
	302	Trace	9.1	99+
	15	0.6	9.5	97
	5	0.35	11.5	93
Iron	13	2.4	9.1	82
	17	0.1	10.8	99+
	2.0	1.2(2)	10.5	40
Manganese	2.3	<0.1	10.8	96
	2.0	1.1(1)	10.5	45
	94	17	9	82
	94	0.15	10	99.8
	94	<0.1	11	99.9+
Zinc	17	0.3	9.5	98

(1) 20 mg/l ferric sulfate also added in addition to lime.

(2) These data were from experiments using iron and manganese in the organic form.

TABLE 18

REMOVAL OF HEAVY METALS BY ALUM AND IRON CLARIFICATION

(after Nilsson[95] and Patterson[96])

Constituent	Coagulant	Concentration, mg/l Influent	Effluent
Arsenic	Alum	0.31 - 0.35	0.06
Arsenic	Ferric Sulfate	5	0.06
Barium	Ferric Sulfate	5	0.15
Chromium (+3)	Alum	15	0.2
Chromium (+6)	Alum	3	2.3
Copper	Alum	15	1.7
Copper	Ferrous Sulfate	5	0.16
Lead	Alum	17	1.3
Lead	Ferric Sulfate	5	0.03
Zinc	Alum	17	11.0

Trace Metal	Percent Removal
Ag (Ag^+)	85.5
Cd (Cd^{++})	92.3
Cr ($Cr_2O_7^{--}$)	94.1
Se (SeO_3^{-3})	33.7

Concentrations of these metals in the trickling filter effluent varied from about 13 to 55 µg/l.

The overall efficiencies for removal of inorganic chemicals in full scale AWT plants at Colorado Springs, Colorado, South Lake Tahoe, California and Orange County, California are also summarized in Table 14 in the previous section on activated carbon. These three plants all treat secondary effluent by lime clarification, filtration and granular activated carbon adsorption and all three produce effluent with inorganic chemical concentrations less than the drinking water MCL.

The results of several years study at Dallas, Texas[101] are summarized. Typically, the incoming concentrations for the metals listed are low, consistent with ranges of metals in municipal wastewater. The activated sludge process reduces these concentrations by 21 to 69 percent. Activated sludge is followed by AWT: lime clarification (at pH 11.5), filtration and activated carbon. The cumulative removals range from 39 to 96 percent, producing the residuals shown in the last column of Table 19.

Reverse osmosis is effective for the removal of most inorganic chemicals. Typically 95 to over 99 percent of metals and other inorganic chemicals listed in the Drinking Water Regulations can be removed by reverse osmosis. Also, as mentioned previously, bacteria, turbidity, color and many organic chemicals are efficiently removed in this process.

Arsenic

The principal forms of arsenic in water are the anions arsenite (AsO_2^-, arsenic valence +3) and arsenate (AsO_4^{-3}, arsenic valence +5). The ingestion of as little as 100 mg of arsenic can result in severe poisoning. In general, inorganic arsenic is more toxic to humans and animals than organic arsenic compounds and the trivalent form (arsenite) is more toxic than the pentavalent form (arsenate). Chronic arsenic exposure results in various kidney, liver and bone disorders. There is some evidence that arsenic is carcinogenic. In many cases where arsenic has been detected in natural waters, it was present in concentrations exceeding the MCL of 0.05 mg/l. Arsenic concentrations have exceeded the MCL is streams far more than any other potentially toxic constituent.

Arsenic is present in the environment in several forms and from several sources. Arsenic is present in rocks in several forms including arsenides, in some mineral veins as native arsenic and as oxides of arsenic. Other sources of arsenic in the environment include: (1) combustion of fossil fuel, (2) pesticides, herbicides and insecticides, (3) mine tailings, (4) by-product of copper, gold and lead refining, (5) several other industrial processes, and (6) as a constituent in some phosphate detergent builders and presoaks.

TABLE 19

REMOVAL OF METALS AT DALLAS AWT PLANT

(after Cohen[101])

Metal	Plant Influent mg/l	Removal (percent) Activated Sludge	Removal (percent) Activated Sludge plus AWT	Effluent mg/l
Cadmium	0.013	39	39	0.008
Chromium	0.215	57	96	0.009
Copper	0.092	33	56	0.041
Mercury	0.00051	69	86	0.00007
Nickel	0.073	21	74	0.019
Lead	0.095	56	53	0.045
Zinc	0.320	65	91	0.029

Note:

1. AWT consists of lime clarification, filtration and activated carbon adsorption.
2. Effluent is after both activated sludge and AWT processes.

The soluble concentration of arsenic depends upon its chemical form and pH. Elemental arsenic is essentially insoluble in water, but many of the arsenates are highly soluble. It has been suggested that arsenic may be oxidized from 0 to +3 to +5, that ligand exchange reactions with OH^-, H_2O and S^{-2} may occur, and that removal may occur through precipitation, sorption and biological uptake.[102] In a particular water, arsenic may be present in various chemical forms that will react differently in treatment processes.

It is believed that chemical oxidation of arsenite is not an important process in natural waters but that rapid oxidation is catalyzed by bacteria. In fresh surface waters there is likely to be a partitioning of arsenic between the oxidation states. Depending on the arsenic sources, the relative rates of chemical and bacterial oxidation of As^{+3}, the rate of bacterial reduction of As^{+5} and the presence or absence of an anaerobic zone, the As^{+3} content could be large or small. Although the concentrations of the species are important, there is little information on the forms present in water and wastewater. No measurements in freshwaters are reported, and information about the rates of the reactions is insufficient to make predictions.[102]

Water Treatment - Pentavalent arsenic can be removed from water by conventional chemical clarification with lime, alum or iron salts as coagulants. Trivalent arsenic is not effectively removed by chemical clarification; therefore, it must be oxidized to the pentavalent form with agents such as chlorine, ozone or potassium permanganate prior to clarification. Based on laboratory and pilot tests, a small 40,000 gpd (150 cu m/day) water treatment plant was constructed in Taiwan to remove arsenic from ground water. During a four month period in 1969, a range in raw water arsenic concentrations of 0.36 to 0.56 mg/l was reduced to trace levels by a treatment system consisting of chlorination, chemical clarification with ferric chloride and filtration.[103]

It is possible to obtain nearly complete removals of anionic forms of arsenic (arsenite and arsenate) by ion exchange resins. Laboratory experiments also indicate that arsenic can be removed by activated alumina. Arsenic also may be removed by reverse osmosis and adsorption on activated carbon although quantitative data are lacking. Activated carbon is reported to have high adsorption potential for pentavalent arsenic.[98]

Wastewater Treatment - Arsenic removals averaged 51 percent in four California activated sludge plants.[16] Arsenic concentrations in raw wastewater at two San Francisco plants were 0.0037 and 0.0031 mg/l and corresponding levels in the activated sludge effluent were 0.0016 (57 percent removal) and 0.0021 (32 percent removal).

The physical-chemical treatment methods used for removal of arsenic from both water and wastewater are similar. Treatment methods reported by Patterson[96] include: (1) sulfide precipitation as the sulfide or ferrisulfide and (2) complexation with polyvalent heavy metals such as ferric iron and coprecipitation with the metal hydroxide, plus adsorption into coagulant floc, with enmeshment of particulate arsenic. This second process is typical of the chemical clarification process used in water treatment. Other processes used, with varying degrees of success include adsorption onto activated carbon and alumina and ion exchange. Treatment methods and removal efficiencies, based on data from Patterson,[96] are summarized in Table 20.

Table 20

ARSENIC TREATMENT METHODS

(after Patterson[96])

Treatment Method	Arsenic Concentration, mg/l Influent	Arsenic Concentration, mg/l Effluent	Percent Removal
Chemical Clarification			
Lime	0.2	0.03	85
Lime	0.5	0.03	95
Lime plus Iron	-	0.05	-
Alum	0.35	0.003 - 0.005	85 - 92
Ferric Sulfate	0.31 - 0.35	0.003 - 0.006	98 - 99
Ferric Sulfate	25.0	5	80
Ferric Chloride	3.0	0.05	98
Ferric Chloride	0.58 - 0.90	0.0 - 0.13	81 - >99
Activated Carbon Adsorption	0.2	0.06	70

Physical-chemical treatment by chemical clarification and activated carbon adsorption studied at the EPA research laboratory in Cincinnati[101, 104] reduced arsenic in raw wastewater from 5.0 mg/l to 0.145 - 0.800 mg/l.

Barium

Barium has toxic effects on the heart, blood vessels and nerves. Soluble barium salts are very toxic whereas the insoluble compounds are generally non-toxic. There is no information available on the chronic effects of low levels of barium ingested over a prolonged period of time. Barium is included in the Drinking Water Regulations because of the seriousness of its toxic effect. Barium generally is not a problem in most water supplies, but there have been occasions when concentrations have exceeded the MCL of 1 mg/l. In most surface water supplies and ground waters, only traces of barium are present but up to 10 mg/l have been found in some water supplies.

In mineral form, barium often occurs as barium sulfate (barite), which has a low solubility. Because most natural waters contain sulfate, barium will dissolve only in trace amounts. However, barium becomes increasingly soluble in the presence of chloride and other anions and cations in dilute solutions.[105]

Barium as barite (barium sulfate) principally is used in drilling muds for oil and gas well-drilling operations. Barite and other barium compounds also are used in the production of glass, paints, rubber, ceramics, and many chemicals. However, very little is known with respect to actual concentrations of barium in various industrial effluents.[106]

Water Treatment - Barium can be removed effectively from water either by lime softening or by ion exchange. Lime softening pilot plant tests on water containing 10-12 mg/l of barium at pH 9.2, 10.5, and 11.6 resulted in removals of 84, 93 and 82 percent, respectively.[48] Samples from two full-scale lime softening plants showed removals of 88 and 95 percent, where the raw water contained barium concentrations of 7.5 and 17.4, respectively. A full-scale ion exchange softening plant achieved a barium reduction from 11.7 to 0.18 mg/l, (98 percent removal).[107]

Wastewater Treatment - In explosives manufacturing, barium was removed by precipitation as barium sulfate upon addition of sodium sulfate. Other wastewater treatment techniques cited by Patterson[96] are summarized in Table 21 and include ion exchange and precipitation as barium carbonate at pH 10 to 10.5 with lime used for pH adjustment.

At the Orange County Water District advanced wastewater treatment plant in California, secondary effluent with a barium concentration of .082 mg/l was reduced to .040 mg/l by lime clarification. The concentration was further reduced to .030 mg/l by filtration which resulted in an overall removal of 65 percent.

Cadmium

Cadmium in the body is believed to be a non-beneficial, nonessential element of high acute and chronic toxic potential. The concentration and not the absolute amount is believed to determine the acute toxicity and equivalent cadmium concentrations in water are considered more toxic than in food. The USGS data for various streams in the United States indicates that cadmium concentrations may range from less than 0.002 mg/l to a high of 0.120 mg/l.

TABLE 21

BARIUM TREATMENT METHODS

(after Patterson[96])

Method	pH	Barium Concentration, mg/l		Percent Removal
		Initial	Final	
Precipitation				
Sulfate	6.0	5.0	0.27	95
Sulfate	10.0	5.0	0.03	99
Sulfate	--	--	0.5	--
Sulfate	7.5 - 8.0	7.0 - 8.6	2.1 - 2.6	70
Carbonate	10.5	7.0 - 8.0	0.15	98
Hydroxide	11.5	5.0	0.94	81
Ion Exchange	--	11.7	0.17	98
Ion Exchange	--	--	--	99.9+
Ion Exchange	--	--	--	99

A typical value for cadmium, however, is expected to be near 0.002 mg/l as compared to the drinking water MCL of 0.010 mg/l. Consequently, cadmium generally should not present a major problem in most water supplies.

Although only trace quantities of cadmium are likely to be found in natural waters, significant quantities of cadmium may be introduced into a water supply through a number of sources. The electroplating industry is the largest user of cadmium metal and currently is the major source of cadmium waste.[106] Other principal sources of cadmium wastewaters include waste sludges from paint manufacturing, paint residue left in used paint containers, and wash water used in battery manufacturing. Other industrial processes which constitute potential sources of cadmium wastewater include metallurgical alloying, ceramic manufacturing, textile printing, chemical industries, and mine drainage.

Water Treatment - Waters containing up to 0.50 mg/l cadmium can be treated by lime softening to achieve the MCL of 0.010 mg/l. Laboratory experiments and pilot plant studies showed that greater than 98 percent removal in the 8.5 to 11.3 pH range could be achieved on ground water containing 0.3 mg/l of cadmium.[48]

Cadmium removal by ferric sulfate and alum clarification are effective, but somewhat lower than removal by lime softening. For ferric sulfate clarification, 90 percent removal is possible at pH values above 8. Data on alum clarification indicate that cadmium removal is dependent on both the turbidity and pH of the raw water.

At initial cadmium concentrations ranging from 0.010 to 0.10 mg/l, cadmium may be removed coincidently in treatment of high coliform waters, and waters with moderate to high turbidity. However, proper pH conditions must be maintained and sufficient coagulant must be used to achieve satisfactory results.

Wastewater Treatment - Five activated sludge plants in the United States achieved an average cadmium removal of 61 percent. Cadmium concentrations in the raw influent at two of these plants were .0059 and .0039 mg/l. After activated sludge treatment the concentrations were reduced to 0.0011 mg/l (81 percent removal) and 0.0026 mg/l (33 percent removal).[16]

The most common method of cadmium removal from wastewater is chemical clarification followed by filtration. Cadmium forms soluble complexes with chemicals such as ammonia and cyanide, making precipitation of cadmium impossible. When such complexing agents are present in the wastewater, pretreatment to remove these agents is required. Other methods of treatment involve ion exchange, solvent extraction, and electrolytic deposition, although use of these methods generally is confined to situations where recovery of the metal is desired.

Patterson[96] and Sittig[106] cite studies that indicate effective cadmium hydroxide precipitation occurs between pH 9.5 and 12.5. Coprecipitation with iron hydroxide or aluminium hydroxide also is effective in cadmium removal. In pilot plant studies of metals in municipal wastewater, three techniques were studied: (1) ferrous sulfate addition at pH 6, (2) low lime plus ferrous sulfate at pH 10, and (3) high lime at pH 11.5. In each of the three techniques, flocculation and settling were followed by mixed-media filtration and carbon adsorption. Of the three techniques investigated, the high lime process achieved the best results with 99.7 percent removal of cadmium.[104] There have been cases where lime clarification has provided sufficient cadmium removal, without the need for filtration.[96,106] However, it is also evident that lime clarification followed by filtration and activated carbon achieves progressively higher removal rates for cadmium.[106,108]

At the Orange County Water District plant in California, cadmium concentrations in the influent ranged from 0.011 to 0.022 mg/l. Following lime clarification, ammonia stripping, recarbonation, filtration, activated carbon adsorption and chlorination, the effluent concentration was 0.00 to 0.005 mg/l. The removal efficiency varied between 74 and 100 percent, with the average being 89 percent.[108]

Chromium

Chromium has not been proved to be an essential or beneficial element in the body but some studies indicate it may be essential in minute quantities. Chromium can exist in water as both the trivalent (Cr^{+3}) and hexavalent (Cr^{+6}) ion and the hexavalent state is more toxic to humans.

Naturally occurring chromium usually is found in the form of chromite (Cr_2O_3), or as chrome iron ore ($FeO \cdot Cr_2O_3$). In natural waters, only traces of chromium in the trivalent state normally occur unless the pH is very low. However, under strong oxidizing conditions, chromium can be converted to the hexavalent state and can occur as chromate (CrO_4^{-2}) or dichromate ($Cr_2O_7^{-2}$), both of which normally indicate pollution by industrial waste. Because of its broad industrial applications, chromium has been introduced into natural waters from a number of sources. The major source of waste chromium is from the metal plating industry, with the automobile parts manufacturers being one of the largest producers. Other major applications of chromium include alloy preparation; tanning; corrosion inhibition; wood preservation; electroplating; and pigments for inks, dyes, and paints.

The hexavalent form of chromium is more toxic and also is more difficult to remove from water and wastewater. Because hexavalent chromium is more difficult to treat than the trivalent form, hexavalent chromium treatment often involves reduction to the trivalent state prior to removal.

Water Treatment - Research by Zemansky[94] involving 12 water treatment plants indicates that chromium is slightly removed by microstraining and clarification, but generally not removed by the filtration process. The study showed that an average 31 percent chromium removal occurred for the 12 water treatment plants.

Methods available specifically to treat water for trivalent chromium include chemical clarification with alum, iron salts or lime. Laboratory studies show that chromium removal by lime clarification is highly dependent on pH.[48] Optimum removal (greater than 98 percent) occurs in the pH range of 10.6 to 11.3. The same removal efficiency is possible over a larger pH range (6.5 to 9.3) using ferric sulfate. Alum coagulation in the same study achieved 90 percent removal in the 6.7 to 8.5 pH range. Greater than 99 percent removal of hexavalent chromium is possible using a special ferrous sulfate coagulation process in which pH adjustment to the 6.5 to 9.3 range is made several minutes after coagulation. This pH adjustment procedure following coagulation provides time to reduce Cr^{+6} to Cr^{+3} prior to floc formation.

Other methods of chromium removal suggested in the literature include reverse osmosis and adsorption by activated carbon, although no actual pilot plant or full-scale plant operation data are available. Activated carbon is reported to have the ability to reduce hexavalent chromium to the trivalent form.[98]

Wastewater Treatment - Conventional activated sludge systems at six wastewater treatment plants averaged 78 percent removal of chromium.[16] Actual removals for the plants ranged from 62 to 93 percent. Another study of conventional secondary treatment plants showed that chromium removal averaged 19 percent and 36 percent, respectively, for trickling filter and activated sludge systems.[11]

Physical-chemical systems using three different chemical clarification systems were studied for metal removal: (1) ferrous sulfate addition at pH 6, (2) low lime plus ferrous sulfate at pH 10, and (3) high lime at pH 11.5. Approximately 99 percent Cr^{+3} removal was achieved following filtration.[104] Activated carbon increased removals to as high as 99.9 percent. The same processes achieved hexavalent chromium removal ranging from 25 to 63 percent following filtration. Activated carbon with any one of the three processes increased hexavalent chromium removal to the 98-99 percent level.

Influent with a Cr^{+6} concentration of 0.204 mg/l was reduced to .096 mg/l by lime clarification at the Orange County Water District plant in California. After filtration followed by activated carbon adsorption, the final effluent concentration was 0.048 mg/l, resulting in 76.5 percent removal for the entire plant.

Among the treatment techniques for hexavalent chromium identified by Patterson[96] and Sittig[106] are (1) reduction to the trivalent state followed by precipitation, (2) ion exchange, (3) evaporative recovery, and (4) reverse osmosis. Reduction normally is accomplished by lowering the pH to 3.0 or less using sulfuric acid, and converting the hexavalent chromium to the trivalent state with a chemical reducing agent such as sulfur dioxide, sodium bisulfite, or ferrous sulfate. This process is then followed by precipitation, usually with lime, to remove the trivalent chromium. These methods have been used to treat industrial wastes, however, no data are available on municipal treatment applications.

Fluoride

Fluoride is a normal constituent of all diets and is an essential nutrient. The only harmful effect of excessive fluoride in drinking water observed in the United States is spotting or mottling of the enamel of teeth. The optimum level of fluoride in the diet will prevent tooth decay. The optimum fluoride level in drinking water depends on the climate because the amount of water consumed is affected by the air temperature.

Most fluorides are low in solubility; consequently, naturally occurring fluorides in a water supply usually are quite limited. As a salt, fluoride is moderately insoluble. There are a considerable number of fluoride-bearing minerals which constitute a source for fluoride in some waters of the United States, but in general, fluoride is not often found in excessive concentrations. Soluble fluorides from industrial wastewaters, however, are much more common. Industries that discharge significant quantities of fluoride are listed below, together with the corresponding form of fluoride typically found in the effluent:[96]

Glass and Plating Industry	HF or F^-, depending on the pH of the waste.
Fertilizer Manufacturing	SiF_4
Aluminum Processing	Na_3AlF_6

Other industrial sources of fluoride wastewater include: electronics manufacturing, ceramics manufacturing, aircraft industries, and mineral and mining operations.[109]

Water Treatment - There are a variety of treatment methods available for removing fluorides from water. These methods include ion exchange, chemical precipitation with alum and/or lime, electrodialysis, and reverse osmosis. Waters containing excessive fluoride ion can be treated for reduction to the MCL by ion exchange using synthetic resins, activated alumina or bone char. Efficiency of fluoride removal using these materials, however, is pH dependent: the lower the pH, the more effective the removal of fluoride. Harmon and Kalichman[110] report several successful full-scale treatment plants in California using these media. Activated alumina has been used successfully in a 500 cu ft bed in Bartlett, Texas since 1952. In this plant, fluoride is reduced from 8 mg/l to 1 mg/l.[96]

Fluoride may be removed coincidently in lime softening of high magnesium water. The actual fluoride reduction accomplished by this technique is dependent upon both the initial fluoride concentration and the amount of magnesium removed in the softening process.

Electrodialysis and reverse osmosis were among the treatment techniques evaluated for the removal of fluoride from ground water in Arizona. Based on small-scale tests, it was estimated that a four-stage electrodialysis system could reduce the TDS from 1,100 mg/l to about 50 mg/l and reduce the fluoride concentration from 6 mg/l to 1 mg/l. For the same raw water, reverse osmosis would produce water with higher TDS (100 mg/l) but lower fluoride concentration (0.6 mg/l) than water treated by electrodialysis.

Wastewater Treatment - Removal of fluoride generally is accomplished by precipitation or by adsorption. Chemicals used for precipitation methods include lime, alum, and magnesium compounds. Removal by adsorption has been accomplished successfully using activated alumina, bone char and ion exchange resins. Table 22 summarizes these treatment techniques and their respective removal efficiencies.

Lime addition is the most commonly used treatment method for the removal of fluoride from wastewater. Patterson[96] reports several successful lime treatment plants, including one where fluoride was reduced from 200 to 3 mg/l at a pH above 12. Findings by Parker and Fong[109] indicate that fluoride removal is dependent on both pH and the presence of other dissolved ions. A minimum fluoride concentration point occurs at pH 8, while a second, somewhat lower residual is achieved in a pH range from 12 to 12.5. For waters of low hardness, simple alum addition plus small amounts of lime for pH control can be used to reduce residual fluoride concentrations to 1-4 mg/l.

TABLE 22

SUMMARY OF FLUORIDE TREATMENT PROCESSES AND LEVELS OF TREATMENT ACHIEVED

(after Patterson[96])

Treatment Process	Fluoride Concentration (mg/l)		Current Application
	Initial	Final	
Lime Addition	--	10	Industrial
Lime Addition	1000 - 3000	20	Industrial
Lime Addition	1000 - 3000	7-8 (after 24-hr settling)	Industrial
Lime Addition	500 - 1000	20 - 40	Industrial
Lime Addition	200 - 700	6 (16-hr settling)	Industrial
Lime Addition	45	8	Industrial
Lime Addition	4 - 20	5.8 (ave.)	Industrial
Lime Addition	590	80	Industrial
Lime + Calcium Chloride	--	12	Industrial
Lime + Alum	--	1.5	Industrial
Alum	3.6	0.6 - 1.5	Municipal
Alum	60	2	Lab Scale
Hydroxylapatite Beds			
synthetic	12 - 13	0.5 - 0.7	Municipal
synthetic	10	1.6	Municipal
bone char	6.5	1.5	Municipal
bone char	9 - 12	0.6	Municipal
Alumina Contact Beds	8	1	Municipal
Alumina Contact Beds	9	1.3	Industrial (lab scale)
Alumina Contact Beds	20 - 40	2 - 3	Industrial (pilot scale)

Lead

Lead is toxic in both acute and chronic exposures. The major risk of lead in water is to small children resulting in brain and kidney damage and other disorders. Because of its widespread presence in the environment, the MCL in drinking water was established as low as practicable.

Lead occurs in rocks primarily as sulfide or oxide forms, and lead concentrations of 0.4 to 0.8 mg/l can occur in natural waters as the result of solution of lead-bearing minerals.[105] The extensive use of lead compounds as gasoline additives has greatly increased the availability of lead for solution in natural waters through automobile exhaust emissions. Studies by Hem and Durum[111] suggest that geographic pattern for lead in rain water has a significant effect on the lead content of surface waters.

Major industrial sources of lead include storage battery manufacture, printing, pigments, fuels, photographic materials, and matches and explosives manufacturing. The storage battery industry is the single largest consumer of lead, followed by the petroleum industry in providing lead compounds for gasoline additives. Lead mines, mining, and smelting also are sources of lead wastewater.

Lead hydroxide and carbonate solubilities tend to control the concentration of lead that may be present in natural waters; the solubility limit is low for more alkaline and moderately mineralized waters.[105,111] Lead concentrations in drinking water are more likely to comply with the regulations in water having a pH near 8 and bicarbonate concentration in excess of 100 mg/l.

Water Treatment - Because of the insolubility of lead in the carbonate or hydroxide form, it is relatively easy to remove from water by conventional treatment methods.[111] In a study of 12 conventional water treatment plants, detectable concentrations of lead were found in 95 percent of the plants.[94] The efficiency of lead removal achieved by these plants averaged 32 percent. Ferric sulfate and alum clarification are capable of achieving 80 to 95 percent removal on raw water containing up to 10 mg/l of lead in the pH range of 6 to 10. Lead can also be removed effectively by lime clarification. Solutions of lead nitrate and lead acetate showed poor adsorption on activated carbon at pH 2, but fairly good removal at pH 5.[98]

Wastewater Treatment - Lead was reduced by an average of 82 percent in six activated sludge plants.[16] Actual removal efficiencies ranged from a low of 71 percent to a high of 92.

Treatment of soluble lead in wastewater often involves the formation of a lead precipitate followed by sedimentation. Precipitation chemicals used include lime, soda-ash, and phosphate. In one plant, lead was reduced from 0.31 mg/l down to 0.1 mg/l by lime treatment and settling.[96] Other methods of lead treatment reported in the literature include ion exchange, and coagulation using ferrous and ferric sulfate.

Chemical clarification with lime, ferric sulfate, alum, and ferric chloride followed by filtration accounted for approximately 99 percent removal of lead in several physical-chemical pilot plants treating raw wastewater.[101,104] Activated carbon treatment in these plants increased removal to as high as 99.6 percent.

Lead removal at two advanced wastewater treatment facilities were 50 percent at the full scale plant in Orange County, California and 53 percent at the Dallas, Texas pilot plant. The removal efficiencies for these plants appear to be low in comparison to removals in physical-chemical systems treating raw wastewater; however, the lead concentrations entering the AWT systems are much lower (i.e. typical values ranging from 0.035 to 0.095 mg/l at the AWT plants and 5.0 mg/l at the pilot plants treating raw wastewater).

Mercury

Mercury poisoning may be acute or toxic. Sublethal dosages result in several disorders including a cerebral palsy-like disease. The toxicity of mercury varies considerably with its chemical form. Monovalent mercury is quite non-toxic since its salts have a low solubility. Inorganic mercury compounds which form water-soluble inorganic salts are among the least toxic forms of mercury occurring in water. Divalent, organic, and elemental mercury, on the other hand, are highly toxic. As previously shown in Table 10 normal background levels of mercury in natural waters range from less than 0.5 to 5.0 μg/l. The risk from mercury in fish is much greater than from mercury in water.

Elemental mercury is soluble in oxygenated waters and may form mercuric oxide salts. These salts, in turn may be adsorbed by minerals and bottom sediments of lakes and streams which tends to prevent natural waters from carrying excessive concentrations of mercury except under unusual conditions.[105] The principal industrial user and discharger of mercury is in chloralkali manufacturing.[106 112] Other major sources of mercury wastewaters include the electrical and electronics industry, explosives manufacturers, the photographic industry, chemical processing, the agricultural industry, the pulp and paper industries, the pharmaceutical industry, and paint manufacturers.

There are several treatment methods available for the removal of mercury from water and wastewaters and the form of mercury must be determined before a proper treatment method can be selected. In general, the organic form of mercury is more difficult to remove from water and wastewater.

Water Treatment - Inorganic mercury can be removed from drinking water by ion exchange, chemical clarification, lime softening and activated carbon adsorption.

Chemical clarification using alum or ferric sulfate is effective in removing inorganic mercury. Research by Logsdon and Symons[113] demonstrated that mercury removal percentages were relatively constant for varying concentrations of mercury in the range of 3 to 16 μg/l. The research further indicated that inorganic mercury removals using alum, steadily increased as turbidity increased, while coagulation with ferric sulfate was independent of turbidity. Typical removal percentages using alum or ferric sulfate are as follows:[48]

pH	Coagulant	Percent Removal Inorganic Mercury
7	Ferric Sulfate	66
7	Alum	47
8	Ferric Sulfate	97
8	Alum	38

For alum clarification, inorganic mercury removal increased from 10 percent on a water with turbidity of 2 TU to 60 percent on water with 100 TU. Lime softening in the pH range of 10.6 to 11.0 can remove 60 - 80 percent inorganic mercury. However, at a lower pH (9.4), removal drops to only 30 percent.

Several studies of powdered activated carbon indicate that removal of inorganic mercury increases as carbon dosage and contact time are increased. Research by Thiem[99] showed that mercury removal using activated carbon is enhanced by the presence of calcium ion, or with the addition of a chelating agent such as EDTA or tannic acid. These chemicals increased mercury removal 10 to 30 percent over removals obtained by carbon alone. Logsdon and Symons[113] found that mercury removal by alum alone was only 40 percent, but the addition of activated carbon increased removals to greater than 70 percent. Other studies show that 80 percent removal of 20 - 29 μg/l of inorganic mercury is possible with a 3.5 minute contact time with granular activated carbon beds.[48]

Ion exchange and activated carbon adsorption are effective methods for organic mercury removal. Removals of 98 percent have been achieved with ion exchange and 80 percent using granular activated carbon. Research by Sigworth and Smith[98] indicates that removals of 90 to over 99 percent are possible in the low concentration range using beds of granular activated carbon.

Wastewater Treatment - The activated sludge process can provide substantial removals of mercury from wastewater. Data from three plants averaged 72 percent mercury removal.[16]

The most common methods of treatment for removal of mercury from wastewater include chemical clarification, ion exchange, adsorption and reduction of ionic mercury to the elemental form and removal by filtration. For high initial concentrations of mercury, sulfide addition to precipitate mercury sulfide will achieve greater than 99.9 percent removal at alkaline pH.[96] However, this method does not appear to be capable of producing effluent mercury concentrations below 10 to 20 μg/l. Ion exchange treatment for inorganic mercury can achieve effluent concentrations of 1 to 5 μg/l.

Physical-chemical treatment processes are effective in removing mercury from wastewaters. In pilot plant studies, lime coagulation at a dosage of 600 mg/l, followed by clarification and filtration achieved 70 percent mercury removal where the initial concentration was 0.5 mg/l, and activated carbon adsorption increased removal to approximately 91 percent.[104] Studies show that activated carbon preceded by coagulation with ferric chloride or alum can reduce initial concentrations of mercury at 0.5 mg/l by 98 and 98.3 percent respectively for the two coagulants.[101]

Several other treatment processes have been developed by various industries for the removal of mercury from wastewater, but removal efficiency data for these processes are limited.

Nitrate

Nitrate in drinking water can cause methemoglobinemia in infants less than three months old. Serious and sometimes fatal poisonings have occurred in infants consuming water containing more than 10 mg/l nitrate nitrogen. Older children and adults are apparently not affected. Nitrate (NO_3^-) is the principal form of nitrogen found in most natural waters. Nitrate also is the most highly oxidized form of nitrogen and usually is very stable in both ground and surface waters when there is a sufficient quantity of oxygen available.

High concentrations of nitrate normally are not found in most surface waters, unless such supplies have been contaminated from sewage or other sources. In surface waters, nitrate concentrations seldom exceed 3 mg/l and often are less than 1 mg/l. In ground waters, nitrate concentrations may range from near zero to 1,000 mg/l. In some cases, the high concentrations can be traced to barnyard pollution or water percolating through soil which has been repeatedly fertilized.

Small quantities of nitrogen contained in igneous rock provide a minor source for the nitrate found in water supplies. More significant sources of nitrate in both surface and ground water include nitrogen in plant debris, animal excrement and fertilizers. Also, ammonia nitrogen present in wastewater effluent may be oxidized to nitrate when discharged to receiving waters.

Water Treatment - The methods currently available for removing nitrate from water are ion exchange and reverse osmosis. A full scale plant in Long Island, New York using a strong anion exchange resin reduces nitrate levels from 20-30 mg/l in the ground water to 0.5 mg/l achieving a removal efficiency of 97.5 to 98.3 percent.[48] Nitrate can be reduced by 60-80 percent by reverse osmosis.

Wastewater Treatment - Ammonia nitrogen present in wastewater effluent may be oxidized to nitrate in the receiving stream. Then, denitrification may occur in bottom sediments in the receiving stream reducing nitrate to nitrogen gas. However, should nitrogen removal from wastewater be required to insure satisfactory downstream nitrate concentrations, either biological or physical-chemical nitrogen removal processes should be used. These processes are capable of producing effluents with less than 2 mg/l total nitrogen - substantially less than the 10 mg/l nitrate-nitrogen concentration specified in the Primary Drinking Water Regulations. Nitrogen can be removed from wastewater by several processes including:

1. Biological nitrification - denitrification
2. Selective ion exchange
3. Ammonia stripping
4. Breakpoint chlorination

All of these processes are described in detail in the EPA Process Design Manual for Nitrogen Control[114] and other publications.[115]

Selenium

There are very few documented cases of poisoning from selenium in drinking water and the maximum allowable concentration of selenium is complicated by several factors including: (1) selenium may be an essential element in nutrition, (2) the chemical form of selenium, the protein, vitamin E and trace element content of the diet all apparently affect whether selenium has beneficial or adverse effects. The MCL of 0.01 mg/l is based on the total selenium content and provides a factor of safety to prevent even minor toxic effects in humans. As previously shown in Table 10, selenium concentrations in rivers and streams range from less than 0.001 mg/l to 0.060 mg/l. Typical values normally are about 0.001 mg/l as compared to the drinking water MCL of 0.01 mg/l.

Selenium is chemically similar to sulfur and often occurs with sulfur in mineral veins of rocks. In water, selenium may occur as selenite (SeO_3^{-2}) or in its most oxidized state as selenate (SeO_4^{-2}). In the quadravalent form (valence +4), selenium may appear in ground water, while in the hexavalent form (valence +6), it may occur naturally in both ground and surface waters. Both forms are quite stable and appear to act independently of one another when present in the same water. Selenium may be sorbed on hydroxide precipitates such as $Fe(OH)_3$ or on sediments, so that concentrations found in natural waters normally are very low.[111]

Industries using selenium which may produce selenium wastewaters include paint, pigment and dye producers, electronics, glass manufacturers, and insecticide industries.

Water Treatment - Chemical clarification with lime, ferric sulfate or alum and activated carbon adsorption are ineffective in removing Se^{+6}, and only moderately effective in removing Se^{+4} from water. Of these methods, clarification with ferric sulfate at low pH (less than 7) is the most effective in removing the quadravalent form.[107] In one study, initial concentration of selenium (0.1 mg/l) were reduced by approximately 85 percent using 100 mg/l of ferric sulfate at a pH of 5.5. Other research shows that the same removal efficiency is possible using 30 mg/l of coagulant for Se^{+4} concentrations of 0.03 mg/l. Limited laboratory research also indicates that both Se^{+4} and Se^{+6} may be removed by ion exchange and reverse osmosis, although no actual full scale or pilot plant data are available.[48]

Wastewater Treatment - Selenium present in wastewater treatment plant effluents may be reduced by several methods including chemical clarification, activated carbon adsorption and a sequence of tertiary treatment processes.

Cohen[101] reported 67 percent selenium removal by lime clarification followed by activated carbon when the initial concentration of selenium was 0.06 mg/l. A removal efficiency of 95 percent was reported for higher initial concentrations (0.5 mg/l). Ferric chloride clarification followed by activated carbon resulted in somewhat lower removal efficiencies, 75 and 80 percent respectively, for initial concentrations of 0.05 and 0.1 mg/l. Research cited by Patterson[96] and Culp[108] indicates that activated carbon treatment of secondary effluent could reduce selenium concentrations from 9.3 to 5.9 μg/l, achieving a removal efficiency of 37 percent. Patterson[96] reports the following removals using bench-scale treatment of secondary effluent containing 2.3 μg/l of selenium.

Process	Removal
Lime coagulation - settling	16.2
Cation exchange	0.9
Cation plus anion exchange	99.7
Process sequence*	
1st Sand Filtration	9.5
2nd Activated Carbon	43.2
3rd Cation Exchange	44.7
4th Anion Exchange	99.9

*Cumulative removal after indicated process

Silver

The primary effect on humans of ingesting silver is the permanent blue-gray discoloration of the skin, eyes and mucuous membranes. There are no known toxic effects. The MCL of 0.05 mg/l was established because of the permanent and irreversible nature of the silver discoloration effect.

Although it appears to be relatively uncommon for silver to occur in natural waters, silver in excess of .038 mg/l has been found in some U.S. surface waters. Because many silver salts such as AgCl and Ag_2S are highly insoluble, low levels of soluble silver should be expected in most waters. Silver nitrate is the most common soluble silver salt which could be a significant industrial source of silver in wastewater. This compound is used in porcelain, photographic, electroplating and ink manufacturing industries. Of these sources, the photographic and electroplating industries are the major contributors of soluble silver wastes.

Water Treatment - Laboratory tests show that chemical clarification with ferric sulfate or alum in the 6 to 8 pH range can achieve greater than 70 percent removal with an initial silver concentration of 0.15 mg/l.[48] Settling alone, without the addition of a coagulant achieved 50 percent removal in river water with 30 JTU and 0.15 mg/l of silver. Lime clarification will also remove silver; removal efficiency increases from 70 to 90 percent when the pH is increased from about 9 to 11.5.

Reverse osmosis and adsorption by activated carbon also have been reported to remove silver from water supplies. Laboratory studies indicate that there is a high potential for good adsorbability of silver on activated carbon.[98]

Wastewater Treatment - Four activated sludge plants in the U.S. achieved an average silver removal of 86 percent.[16] The success of activated sludge treatment in removing substantial concentrations of silver from wastewater is supported by Zemansky,[11] who reported an average removal of 71 percent. The AWT plant in Orange County, California, achieved greater than 68 percent removal of silver, reducing silver concentrations in the secondary effluent from 4.0 to 1.3 µg/l. The following summary of pilot plant research by Cohen shows excellent removal of silver by physical-chemical treatment processes.[101]

Chemical Clarification Followed by Carbon Adsorption	Initial Concentration (mg/l)	Residual Concentration (µg/l)	Percent Removal
Coagulant			
Lime	0.5	10	98
Ferric Chloride	0.5	5	99.1
Alum	0.6	5	99.2

Other treatment methods identified by Patterson[96] include precipitation (using chlorine, sulfide, lime, or magnesium sulfate), ion exchange, reductive exchange and electrolytic recovery. Very low residual silver concentrations are possible using ion exchange. Patterson cites one study in which greater than 85 percent removal of trace levels of silver were achieved from an extremely dilute secondary effluent by cation exchange. The same study showed that 91.7 percent removal could be achieved by combined cation and anion exchange.

Copper

Copper is a fairly common trace element in natural water. Copper salts such as sulfate and chloride are very soluble in low pH waters, but, in water of normal alkalinity, these salts hydrolyze and copper may be precipitated. In rocks, copper occurs most commonly as a sulfide which may be oxidized in the process of weathering. Some of the copper may go into solution as sulfate, although a significant amount would be precipitated as carbonate if there is sufficient carbon dioxide in the water. Small quantities may enter the water supply by solution of copper and brass water pipes in contact with water. Copper salts added to open reservoirs for algae control may provide another source of copper in water supplies.

The principal source of industrial copper wastewater is metal cleaning and plating baths. Copper mining wastes and acid mine drainage also contribute significant quantities of dissolved copper to waste streams. Other sources of copper wastewater include pulp and paper mills, wood preserving, fertilizer manufacturing, petroleum refining, paints and pigments, steel works and foundaries, and non-ferrous metal works and foundaries.

Water Treatment - Research by Zemansky[94] indicates that copper is slightly removed by microstraining and that increased removal occurs with clarification and filtration. In plants where copper was removed significantly in the clarification process, no appreciable increase in removal was evident when clarification was followed by filtration. The study showed that an average of 49 percent copper removal occurred in 12 plants using these treatment techniques.

Laboratory tests on water with low concentrations of copper show some adsorption on activated carbon at pH greater than 6.[98] Removal efficiency, however, is reduced as the pH is lowered to a point where no copper removal is achieved at pH 3.

Ion exchange and reverse osmosis are effective methods for removal of copper. Research reported by Furukawa[116] indicated that 99 percent copper removal could be achieved by reverse osmosis.

Wastewater Treatment - Conventional activated sludge systems at six wastewater treatment plants achieved copper removals ranging from 56 to 94 percent.[16] Average removal for the six plants was 80 percent.

Physical-chemical treatment processes are effective in removing copper from wastewaters. In pilot plant studies, chemical clarification with ferric sulfate and filtration achieved 95.6 percent removal of copper and lime clarification followed by activated carbon adsorption reduced copper concentrations by 90 percent.[104] Chemical clarification with ferric chloride or alum used as the coagulant can achieve 96 and 98.3 percent removal for the two coagulants respectively, when followed by activated carbon adsorption.

Copper removal at two advanced wastewater treatment plants were 56 percent at the Dallas, Texas plant,[101] and 91.6 percent in Orange County, California. The copper concentrations in the effluent at the two plants were 41 μg/l and 25 μg/l, respectively.

Other treatment processes cited by Patterson[96] include ion exchange, evaporative recovery, and electrolytic recovery. A pilot scale reverse osmosis plant achieving greater than 99 percent copper removal also was reported.

Iron and Manganese

Iron is one of the most abundant constituents of soils and rocks, but is found in much lower concentrations in natural waters. Iron exists in water either in the bivalent ferrous or the trivalent ferric form, depending on the pH and dissolved oxygen content of the water. Although the chemical behavior of the two states is somewhat different, both may be present simultaneously in the same water. At neutral pH and in the presence of oxygen, ferrous iron (Fe^{+2}) usually is oxidized to the ferric (Fe^{+3}) state which is a much more stable condition. Soluble iron found in many waters, usually occurs in the form of some complex ion which presents considerable difficulty in treatment.

In addition to solution from natural sources, iron may be added to ground water from contact with well casing, piping and other iron objects. In surface waters, suspended sediments also may contain iron. Other sources of iron in water are acid mine drainage, ore milling, chemical industries, metal processing, textile mills, canneries, tanneries, fertilizers, and petroleum refining.

Manganese resembles iron in its chemical behavior and occurrence in natural waters, but is found less frequently and usually at lower concentrations. The solubility of the +2, +3, and +4 oxidation states of manganese depends upon pH, dissolved oxygen and the presence of complexing agents. Occasionally, deep lakes or reservoirs that contain organic sediments under anaerobic reducing conditions can distribute considerable Mn^{+2} throughout the water during turnover mixing. Normally, however, the concentration of manganese in natural surface waters is less than 0.25 mg/l as previously indicated in Table 10.

Treatment Methods - The treatment methods for removal of iron and manganese from water and wastewater are similar. Although ion exchange and reverse osmosis are effective in removing iron and manganese, the predominant treatment process for both metals is oxidation from the soluble form to the insoluble form followed by precipitation.

Most commonly used water treatment methods in the control of iron and manganese include (1) precipitation followed by filtration, (2) ion exchange, and (3) stabilization with polyphosphates. The precipitation and filtration process normally involves aeration, detention (or clarification) and filtration. In many cases, chlorine, potassium permanganate, or lime are added following the aeration process to aid in oxidation.[117] Research by Zemansky[94] involving 12 conventional water treatment plants, indicates that generally high removals (an average of 65 percent) of iron and manganese are achieved. Lime and potassium permanganate additions were considered significant factors in the high removal efficiencies achieved for both metals. Relatively high percentage removals in the clarifier were followed by higher percentage removals in the filters. Patterson[96] reports the following removals of iron at municipal water treatment plants:

Process	Iron Concentration, mg/l	
	Influent	Effluent
Chlorination, alum-lime-sodium silicate precipitation, sand filtration	1.5	0.05
Aeration, lime, sand filtration	2.4	0.0

Process (Cont'd)	Iron Concentration, mg/l Influent	 Effluent
Aeration, sand filtration	2.5	0.13
Aeration, coke bed filtration sedimentation, sand filtration	5.7	0.13
Lime, aeration, diatomite filtration	10	0.1

Although it is doubtful that activated carbon adsorption can compete with precipitation for the removal of iron, studies indicate that ferrous sulfate and ferrous chloride are adsorbed to some extent.[98] Activated carbon displays strong reduction properties, converting ferric salts to the ferrous state in the absence of air. With large concentrations of dissolved oxygen, activated carbon will act as a catalyst for the oxidation of Fe^{+2} to Fe^{+3}, which is easily precipitated at pH above 5.[98] Furukawa[116] reports that reverse osmosis can reduce iron and manganese concentrations by 99 and 98 percent, respectively. Research cited by Patterson[96] indicates excellent removal of iron and manganese by ion exchange. Table 23 summarizes treatment data for one ion exchange unit operating over a three-year period.

The activated sludge process is very effective in removing iron and slightly effective in removing manganese. A study of six activated sludge plants showed total iron to be reduced by an average of 87 percent, and ferrous iron by 61 percent; manganese was reduced by an average of 32 percent.[16] Physical-chemical treatment studies indicate that Mn^{+2} is effectively removed by lime clarification, but removals with iron as the coagulant are very poor.[104] Lime clarification followed by activated carbon adsorption achieved greater than 98 percent removal, while ferric chloride reduced manganese by only 17 percent.

At the advanced wastewater treatment plant in Orange County, California, secondary effluent with an iron concentration of 190 μg/l and manganese concentration of 38 μg/l was reduced to 16 μg/l and 2 μg/l respectively, by lime clarification.

Zinc

The chemical behavior of zinc is very similar to cadmium, with both metals occurring in water in the +2 oxidation state. Zinc chloride and sulfate are very soluble in water, but hydrolyze in solution to reduce the pH. With an excess of carbon dioxide present in solution, it is unlikely that the proper pH will occur to allow zinc to precipitate as hydroxide.

Because zinc is readily adsorbed on sediments and soils, only trace amounts of zinc normally are found in natural ground and surface waters. Significant quantities of zinc, however, may be discharged in industrial waste streams such as plating and metal processing, stainless steel and silver tableware manufacturing, yarn and fabric production, pulp and paper production, and the pigment industry. High concentrations of zinc also are known to occur in acid mine drainage water.

Water Treatment - In a study of 12 conventional water treatment plants, the average zinc removal efficiency was 48 percent.[94] Results of the study indicated that actual removals varied significantly from a low of near zero, to a high of 90 percent.

TABLE 23

IRON AND MANGANESE REMOVAL EFFICIENCY BY ION EXCHANGE TREATMENT

(after Patterson[96])

Constituent	Raw Well Water Concentration mg/l	Treated Water Concentration mg/l
EIGHT MONTHS OF OPERATION		
Total Iron	37	0.5
Total Manganese	1.7	0.1
FIFTEEN MONTHS OF OPERATION		
Total Iron	53	0.3
Total Manganese	1.0	0.0
THIRTY-SIX MONTHS OF OPERATION		
Total Iron	52	0.1
Total Manganese	1.3	0.0

Wastewater Treatment - Conventional activated sludge systems at six treatment plants averaged 72 percent zinc removal.[16] The lowest removal efficiency noted for the six plants was 54 percent while the highest removal was 88 percent. Cohen[101] reported similar removal efficiencies by biological treatment: zinc removal ranged from 35 to 80 percent.

Chemical clarification with ferric chloride, ferric sulfate and lime followed by activated carbon adsorption provides effective removal of zinc from wastewater. In one pilot plant study, 63 percent of the zinc was removed using ferric sulfate, and activated carbon increased removal to approximately 95 percent.[104] The same study demonstrated 85 percent removal using a combination of lime and ferric sulfate, activated carbon providing only a slight increase in overall removal. Zinc removal using lime as the coagulant achieved 76 to 94 percent removal, while ferric chloride resulted in 94 percent removal.

Excellent removal of zinc has been achieved at the advanced wastewater treatment facilities in Dallas, Texas and Orange County, California. In the Texas plant, zinc concentrations of 0.320 mg/l were reduced to 0.029 mg/l, achieving 91 percent removal.[101] Although the California plant provided only 59 percent removal, final effluent concentrations of 0.127 mg/l were still very low in comparison to the drinking water standard of 5 mg/l.

Total Dissolved Solids (TDS)

The inclusion of TDS in the National Secondary Drinking Water Regulations is intended to deal with the aesthetic, or non-health related qualities of drinking water. Inorganic constituents that affect the health of consumers are measured in laboratory tests for TDS, but, except fluoride and nitrate, they are normally present in trace concentrations (less than 1 mg/l). The potentially toxic constituents normally present in trace concentrations are included in the Primary Regulations and are discussed separately in the preceding sections of this report.

Inorganic constituents present in relatively large concentrations that comprise TDS in most natural waters include: calcium, magnesium, sodium, bicarbonate, chloride and sulfate. These ions are ubiquitous constituents of natural waters. They enter water supplies naturally from the leaching of salts such as sodium chloride present in surface and subsurface deposits and from the decomposition of geologic formations. Occasionally, potassium, fluoride and nitrate are present in concentrations above the 1 to 10 mg/l range. Calcium and magnesium are the principal constituents that cause hardness in water, as discussed in the following section.

A TDS limit of 500 mg/l is included in the Secondary Regulations because of taste effects and the fact that drinking water containing a high concentration of TDS is likely to contain an excessive concentration of some specific substance that would be aesthetically objectionable to the consumer. Chloride in reasonable concentrations is not harmful to humans, but in concentrations above 250 mg/l, chloride causes a salty taste in water which is objectionable to many people. Sulfate may cause detectable tastes at concentrations of 300 to 400 mg/l, but some are able to detect as little as 200 mg/l; at concentrations above 600 mg/l, it may have a laxative effect. High concentrations of sulfate also contribute to the formation of scale in boilers and heat exchangers.

The principal concern with respect to sodium relates to its potential health significance rather than to aesthetic effects. However, existing data did not support the establishment of a Maximum Contaminant Level for sodium in the Interim Primary Drinking Water Regulations. It is recommended by EPA that the States institute programs for regular monitoring of the sodium content of drinking water served to the public, and for informing physicians and consumers of the sodium concentration in drinking water. By this means, those affected by high sodium concentrations can make adjustments to their diets, or seek alternate sources of water to be used for drinking and food preparation.

Treatment Methods - Chloride, sulfate and sodium cannot be significantly removed from water or wastewater by conventional biological treatment or by the physical-chemical processes of chemical clarification, filtration or carbon adsorption. The only demonstrated methods currently available to remove these constituents are reverse osmosis, electrodialysis and ion exchange. Both reverse osmosis and electrodialysis are being used to treat municipal water supplies and reverse osmosis is being used to treat wastewater. Ion exchange has been used for many years to produce low TDS waters for various industrial purposes.

Hardness

Hardness is caused by the divalent metal ions calcium, magnesium, strontium, iron and manganese. Calcium and magnesium are the only ions present in most waters in large enough concentrations to cause significant amounts of hardness. Hardness in natural waters is derived primarily from contact with soil and rock formations such as limestone and dolomite which contain calcium carbonate. Hardness is expressed as equivalent calcium carbonate, and waters commonly are classified in terms of the degree of hardness as follows:[118]

0 - 75 mg/l	Soft
75 - 150 mg/l	Moderately hard
150 - 300 mg/l	Hard
over 300 mg/l	Very hard

There have been several studies that indicated a correlation between water hardness and heart disease. Most of the studies indicate an inverse correlation between the incidence of cardiovascular disease and the hardness concentration, i.e., as water hardness decreased, the incidence of heart disease increased. There are uncertainties in the studies conducted to date and no causal relationship between hardness and heart disease has been identified. The study by the National Academy of Sciences considered the potential effect of hardness on human health and the report[1] concludes as follows:

> *"Despite these uncertainties, the evidence is sufficiently compelling to treat the hard water hypothesis as plausible, particularly when the number of potentially preventable deaths from cardiovascular diseases is considered. In the United States, cardiovascular diseases account for more than one-half of about two million deaths that occur each year. On the assumption that water factors are causally implicated,*

it is estimated that optimal conditioning of drinking water could reduce this annual cardiovascular disease mortality rate in the United States by as much as 15%.

In view of this potential health significance, it is essential to ascertain whether water factors are causally linked to the induction of cardiovascular or other diseases and, if so, to identify the specific factors that are involved. Much more definitive information is needed in order to identify what kinds of remedial water treatment, if any, can be considered."

Treatment Methods - Calcium and magnesium can be removed from water by chemical precipitation, ion exchange, reverse osmosis and electrodialysis.

Lime or lime and soda ash have been used in many full scale water treatment plants in the United States to soften municipal water supplies by chemical precipitation. The processes are well developed and are capable of producing water with a hardness of 100 mg/l or less.

Ion exchange has been used in several large water treatment plants in the United States. Small ion exchange units also are used throughout the United States to produce soft water in individual residences. Many of these home water softeners are regenerated on site and the brine is discharged to the sewer. Ion exchange softening produces water with essentially zero hardness. Municipal ion exchange softening plants blend softened and unsoftened water to achieve a hardness of about 100 mg/l for distribution.

Reverse osmosis and electrodialysis are capable of achieving high, but non-selective removals of calcium and magnesium; i.e., reverse osmosis will remove 95 percent or more of most inorganic ions, including calcium and magnesium, present in municipal water or wastewater. The process is somewhat more efficient in the removal of multivalent ions such as calcium and magnesium than monovalent ions such as sodium.

SECTION 6

FACTORS IN THE LOCATION OF WATER INTAKES

GENERAL CONSIDERATIONS

The purpose of this report is to present rationale for interim guidance in the location of new water supply intakes when there is a municipal wastewater discharge upstream. This rationale also applies when a new municipal wastewater treatment plant is to be located upstream from an existing water works intake.

There are a great many factors to be considered regarding intake locations. Many of these factors apply even in the absence of upstream discharges of municipal wastewater. Raw water quality may vary greatly from stream to stream; it is assumed that a preliminary selection among various streams has been made on the basis of best available raw water quality from a public health standpoint and adequate quantity. The problem then becomes one of locating the intake or wastewater treatment plant along a given stream.

For the moment, the question of upstream wastewater discharge is set aside and the other factors are considered. This is done in order to help place the potential hazards of wastewater contaminants in perspective with the risks involved in all water systems even when there is no pollution from wastewater.

Important items in the location of intakes which take into account reliability, safety, and cost include:

1. Adequacy of supply.
2. Channel changes, shoal and bar formation, and silting.
3. Availability of water to intake ports at all river stages and at all stream flows.
4. Accessibility to intake for maintenance at all river stages and at all seasons.
5. Location of the intake with respect to the city to be served.
6. Navigation requirements.
7. 100-year flood level.
8. Need for storage dam, either in-channel or off-channel, and detention provided.
9. Foundation conditions.
10. Structural stability and safety.
11. Protection from rapid currents, wind, ice, boats, floating material, waves, and bottom sediment.
12. Water depth, and ability to draw water from different depths.
13. Distance from service roads and a source of electric power.
14. Protection from vandalism.

Even in the absence of upstream discharges of municipal wastewater, there are public health factors to be considered in intake location. Storm runoff which makes up stream flow may contain almost any of the substances which are limited by the Drinking Water Regulations. The concentrations of these substances can be restricted by proper location and operation of intakes. Runoff from urban areas should be avoided when possible because it is likely to be higher in contaminants than runoff from rural areas. Ability to draw off water from a stream at different depths may give some control over the amounts of turbidity, color, iron, manganese, algae, and other substances in the raw water. Rivers and streams fed by rural and urban runoff can contain many substances of public health significance.

Most streams are subject to accidental spills in the watershed of agricultural chemicals and hazardous materials being transported by truck, rail, or air regardless of whether or not there are planned municipal wastewater discharges. Metals which are picked up from distribution and service piping as a result of corrosion are also independent of water supply source and the question of wastewater content.

Additional hazardous material which may be contributed to raw water in streams by municipal wastewater discharge are principally organics (especially synthetic organics) and some heavy metals which have their only origin of consequence in wastewater. Also, many substances present in streams receiving no wastewater may be present in higher concentrations in streams which do receive municipal wastewater, particularly pathogenic bacteria, virus and other organisms from the intestines of man. In the absence of wastewater discharge, control of treated water quality supplied to the public depends upon monitoring of raw and finished water quality and upon the degree and reliability of water treatment provided.

With the discharge of municipal wastewater upstream of a water intake, another control must be provided in the form of wastewater treatment prior to discharge and the monitoring of effluent quality. The resulting effluent quality depends upon the degree and reliability of wastewater treatment provided. With wastewater discharge to a water source, then, there are three primary forces at work which affect finished water quality: (1) wastewater treatment, (2) purification in the stream, and (3) water treatment. The end product of these three forces must be water of sufficient quality for drinking. The intermediate force, stream purification, may play an important role as compared to the other two where the stream provides great dilution, high rates of reaeration, long travel distance, or prolonged storage. However, the situation of greatest interest is the limiting condition, which, in a particular stream with given flow, dilution and reaeration characteristics, becomes the minimum allowable distance between the points of waste discharge and water supply withdrawal under prevailing conditions.

This minimum separation is not a fixed distance for all situations, but, rather, one which varies widely depending on many local factors, and is a distance which must be decided on a case-by-case basis by qualified local authorities. At present there is an important unresolved question which has a vital impact on whether certain impurities contributed by wastewater are to be removed at their source in the wastewater treatment plant or later in the water purification process. This question arises from the uncertainty as to the minimum raw water quality which can be permitted in streams which are supply sources receiving municipal wastewater and the maximum safe load which can be placed on the water plant. The Drinking

Water Regulations are based on accumulated experience treating waters from relatively unpolluted sources. There are no minimum stream quality standards for water at supply system intakes.

The lack of standards for minimum raw water quality from polluted sources places a considerable restraint on water reuse. Water and wastewater treatment techniques for production of high quality water are quite similar, actually almost identical in many cases. In general it is more economical overall to apply the required treatment process in the water treatment plant rather than the wastewater plant. However, the uncertainty as to the safe load which may be placed on water treatment processes may dictate the use of additional wastewater treatment rather than (or in addition to) additional water treatment.

In making case-by-case judgements of the minimum distance between the points of wastewater discharge and water supply intake, some of the items to be considered include:

1. Stream flow and quality.
2. Quantity and quality of treated wastewater to be discharged.
3. Potential water quality improvement by stream purification processes including dilution, reaeration, adsorption, sedimentation, and biological die away.
4. Pollution from sources other than municipal wastewater including industries, storm runoff, agriculture, and miscellaneous non-point sources.
5. Raw water quality at intake under most adverse conditions.
6. Water treatment provided.
7. Relationship between wastewater effluent characteristics and safe drinking water requirements.
8. Risk assessment of intake siting options.

Historically, one of the basic principles of sanitary engineering has been to locate a city's water supply intake upstream from its own wastewater discharge. This principle has been followed almost without exception. However, the concept of how far downstream a city's water intake must be from a neighboring city's wastewater discharge has changed over the years. Ancient adages persist to our day in statements like "running water purifies itself" and "a river purifies itself every 20 miles" and so forth.

The USPHS Manual of Recommended Water - Sanitation Practice 1946, states that:[119]

> *"Waters containing more than 20,000 coliform bacteria per 100 ml, are unsuitable for use as a source of water supply, unless they can be brought into conformance (coliforms reduced to less than 20,000/100 ml) by means of prolonged preliminary storage, or some other means of equal permanence and reliability."*

Many cities located on the Ohio, Mississippi, Missouri, Kansas and other rivers have successfully produced biologically safe water from raw river water containing from 50,000 to 2,000,000 coliforms/100 ml. This has been accomplished by use of pre-chlorination, pre-sedimentation, storage, double coagulation-sedimentation, and other means. A later USPHS study reported by Walton in 1956[120] concluded that the routine successful treatment of high coliform raw waters indicated that:

> *"The current USPHS recommendations with respect to the density of coliform organisms in raw water acceptable for treatment in modern well operated plants are no longer applicable".*

By effective disinfection of water free from suspended material in a modern water treatment plant, rivers can be deactivated with certainty. In 1969 AWWA Committee Report on Viruses in Water[121] concluded that:

> *"There is no doubt that water can be treated so that it is always free from infectious microorganisms - it will be biologically safe".*

One of the factors which is currently receiving much attention and which is being given much weight is the matter of trace organics. Trihalomethane production during chlorination may be rather high even with relatively low total concentrations of organics. Further, sufficient of these organics will survive natural purification, regardless of time and distance between outfall and intake, to remain a potential problem. The methods of treatment in the wastewater and water treatment plants, particularly in the water treatment plant, appear to be much more important than intake location in the case of trace organics. With contribution of wastewater to water supply streams there is also concern about the organics which have yet to be identified and evaluated for possible health effects. This is true even in cases where the total quantity of all the unidentified organics is low (less than 0.5 mg/l). In this instance, the question is not distance from the point of wastewater introduction, but the complete exclusion of organics originating in municipal wastewater from water supply sources until this potential hazard is better evaluated.

The technical capability of water and wastewater treatment processes for removal of most of the substances of concern was discussed in Section 5 of this report. Despite this capability, the location of a water intake immediately below a municipal wastewater plant outfall should not be considered. Similarly, new sewer lines should not be constructed so as to discharge immediately above an existing water works intake. No serious proposal by even the most avid promoters of wastewater reclamation have ever been made which did not include either surface or underground storage of treated wastewater prior to withdrawal for subsequent water treatment. It would be foolish not to take advantage of natural purification processes in any rational plan of either direct or indirect water reuse. The natural purification processes of dilution, time of travel, separation by distance, sedimentation, bacterial die-away, adsorption, storage and loss-of-identity have many advantages, the most important of which is the time afforded to learn the results of water quality monitoring, to detect accidental spills, and to correct wastewater treatment plant malfunctions.

Thus, it can be said without fear of serious question that zero distance between sewer outfall and water intake is not sufficient. What is adequate? As stated previously, this determination is a judgemental decision to be made by local public health experts and other informed professionals on a case-by-case basis supported by an adequate background of facts and circumstances concerning local conditions. However, in all cases, reaction time to emergencies is a major consideration. From this standpoint it would appear that 24 hours of combined time in travel and storage between wastewater discharge and water supply intake would be a minimum. This, then, is one criterion for intake location.

This may very well be the governing criteria, if it is accepted by health authorities as being sufficient to serve the intended purpose of reaction time. Greater separation in order to obtain more treatment through natural purification would have to be justified on an economic basis. That is, the cost of additional pipeline would have to be less than providing equal removal of the affected contaminants in water treatment, which is doubtful in most situations.

Once the intake location is selected, the question remains as to whether removals of certain substances are to be provided in wastewater or water treatment. There are the items of total costs, local costs, equity of who pays the costs, and incidental benefits of treatment in the upstream location. As shown in the next section, it is cheaper in most cases to minimize wastewater treatment and to maximize water purification. However, it seems more equitable for the city which produces the wastewater to pay for the costs of removing substances which have adverse effects on downstream water supplies, particularly in view of the fact that State and Federal grants may be available for wastewater treatment but not for water treatment. In addition, greater overall protection of the environment, especially of the public health aspects of recreational use of the stream, is provided by removal of undesirable materials nearest their source in the wastewater treatment plant.

The general types of risks involved in drinking water fall into four main categories; toxicological, microbiological, aesthetics, and possible chronic effects of trace organics. The degree of risk with and without wastewater in supply sources and the effects of separation between discharge and intake for these four risk categories are given in the following tabulation. All of these risks can be substantially reduced by providing a high degree of treatment for wastewater prior to release to a stream.

General types of hazards in drinking waters	Degree of risk, with and without wastewater in supply source and effects of separation between discharge and intake.
1. Toxicological (pesticides, residues, mine drainage, accidental spills of chemicals in transport, municipal, industrial, and agricultural wastewaters, urban and rural runoff)	Many surface waters throughout the country are subject to contamination from accidental spills of toxic materials in transport, and some are so contaminated from urban and agricultural runoff and other non-point pollution sources as to make the health risks only slightly different than those involved with use of river water receiving treated municipal wastewater. Increased distance between points of discharge and intake provides more time for detection of toxic materials which have not been removed in treatment. Removal of toxic materials by stream self purification is not as important or effective as that in water or wastewater treatment. AWT processes

can remove nearly all the dissolved and suspended contaminants in wastewater and can provide a high degree of protection against possible toxic contaminants.

2. Microbiological (bacteria, virus, fungii, and other organisms from human wastes.

   Raw municipal wastewater is the principal source of the organisms transmitting water borne disease. Increased distance between wastewater outfall and water intake provides more time for natural die-away of the pathogens. However, in cases of limited separation, any necessary removal up to complete disinfection can be obtained by advanced wastewater treatment prior to effluent discharge. The minimum separation required then, depends upon the degree of removal of pathogens provided prior to discharge and to the reliability in treatment which the plant affords. Because microbiological tests require several days for completion, time in travel or storage in the stream is not a monitoring advantage unless four days or more are available.

3. Aesthetics (acceptance, taste, and odor and color)

   Water from streams which do not receive treated wastewater are more desirable esthetically than water obtained from streams receiving wastewater, and greater separation between outfall and intake, up to a point at least, probably provides greater public acceptance. Physical problems of taste, odor and color may arise from the discharge of wastewaters to water sources, although these problems can be avoided if proper water and wastewater treatment are provided.

4. Possible Chronic Effects of Trace Organics (carcinogens, mutagens, tetratogens)

   Many water supply sources contain trace organics which in themselves, or from the products of their reactions with chlorine, ozone, or other oxidants, may have adverse health effects following long term ingestion of trace amounts (less than 1 mg/l) of such impurities. These organics may originate in nature or be present in wastewater. Wastewater may contain synthetic organics which are not found in nature. Until more is known, it is assumed, that there may be more risks involved in the wider variety of organics found in wastewater. Even though the concentration of total organics is reduced to 1 mg/l or less by adsorption or stream sediments or activated carbon there may still be a health hazard. The extent of the hazard probably is not affected to any practical extent by time of stream travel or storage. Removals of organics by AWT or upgraded water treatment are more important than separation distance between outfall and intake.

STREAM CHARACTERISTICS

Stream flow characteristics and background water quality are discussed in Sections 2 and 3. It is the general conclusion of this review that secondary effluent from municipal treatment plants that receive sewage from residential areas (no industrial wastes) do not contain specific inorganic or organic chemicals in concentrations that exceed the Primary or Secondary Drinking Water Regulations. However, secondary effluent does exceed the regulations for turbidity, coliform bacteria and unspecified organics as measured by foaming agents, color and odor. Although there are no drinking water regulations for the general organic content as measured by COD or TOC, there is concern about the health effects of these organics. There is particular concern when the organics are contributed by wastewater.

The typical concentration of TOC in unpolluted streams is about 10 mg/l and about 40 mg/l in secondary effluent from municipal treatment plants with no organic industrial wastes. Using these levels of organics gives the TOC concentration at various percentages of wastewater in stream flow is shown in Figure 1. This figure shows that the TOC concentration is 25 mg/l when the treated wastewater discharge is equal to the stream flow, or 50 percent of the total flow, decreasing to 13 mg/l when the wastewater is 10 percent of total flow. Also shown in Figure 1 is a curve for the case if the treated wastewater TOC concentration is reduced to 20 mg/l by chemical clarification and filtration after secondary treatment. This illustrates graphically the improvement in stream quality that can be achieved by wastewater treatment.

The effect of reduced stream flow during dry periods would be to increase the TOC concentration. The exception to this occurance would be the case where sufficient advanced treatment is provided to produce wastewater effluent with a TOC concentration below 10 mg/l. Of course, these are average values and both stream flow and effluent quality will vary.

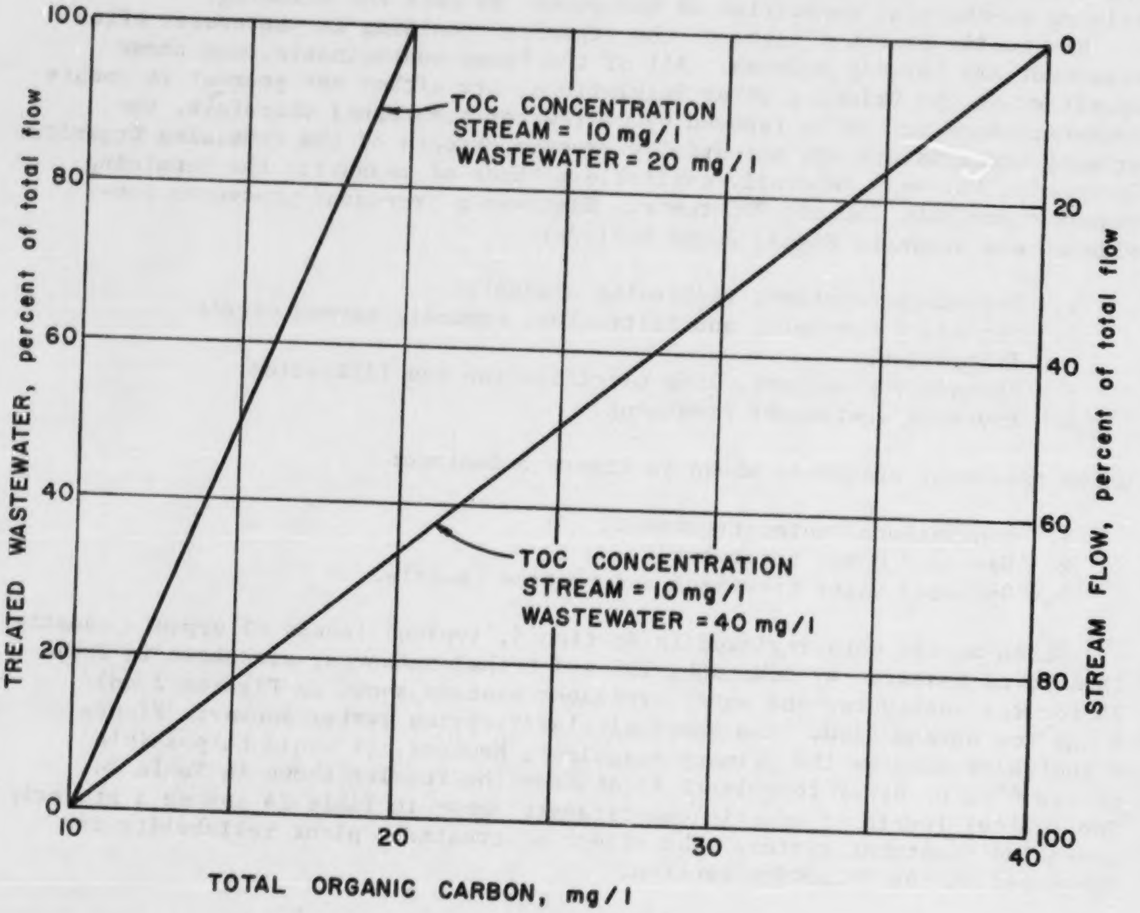


Figure 1. TOC CONCENTRATIONS IN STREAM FLOW & WASTEWATER BLENDS

TREATMENT PROCESS CAPABILITY

The capabilities of water and wastewater treatment processes to remove contaminants listed in the Primary and Secondary Drinking Water Regulations are discussed in detail in Section 5 of this report. Based on this review of treatment capabilities, it is concluded that municipal wastewater that contains little or no industrial waste can be treated to meet all regulations for drinking water. However, the Drinking Water Regulations were not developed to cover wastewater and the regulations were based on the premise that the water source is free of contamination from municipal and industrial wastes. The standards were not intended to be sufficient to insure that water containing substantial quantities of wastewater is safe for drinking.

The public health effects of the organics remaining in wastewater after treatment are largely unknown. All of the known contaminants, and those specified in the Drinking Water Regulations, are either not present in unsafe concentrations or can be removed by wastewater treatment; therefore, the primary concerns are the potentially adverse effects of the remaining organics. Currently, the only generally available methods of measuring the remaining organics are BOD, COD and TOC tests. Wastewater treatment processes considered are shown in Figure 2 and include:

1. Secondary treatment (activated sludge).
2. Secondary treatment and filtration, commonly termed direct filtration.
3. Secondary treatment, lime clarification and filtration.
4. Advanced wastewater treatment.

Water treatment processes shown in Figure 3 include:

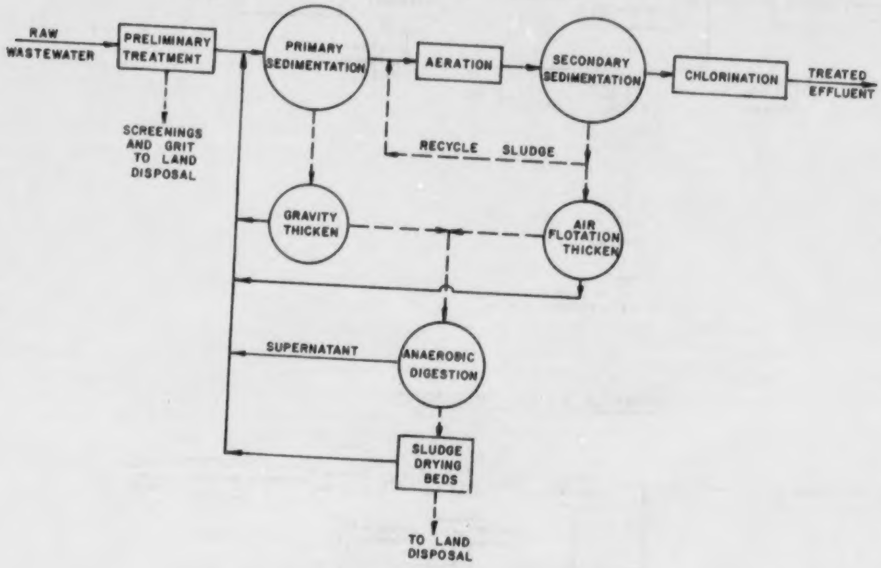
1. Conventional water treatment.
2. Upgraded water treatment.
3. Upgraded water treatment and reverse osmosis.

Based on the data reviewed in Section 5, typical levels of organic constituents, as measured by BOD, COD, TOC and trihalomethanes, are shown in Table 24 for the wastewater and water treatment systems shown in Figures 2 and 3 and for stream flow. The chemical clarification system shown in Figure 2 indicates lime as the primary coagulant; however, it would be possible to use alum or other coagulants to achieve the results shown in Table 24. The typical levels of organic constituents shown in Table 24 assume a properly operating treatment system. The effect of treatment plant reliability is discussed in the following section.

TREATMENT PLANT RELIABILITY CONSIDERATIONS

Water and wastewater treatment plants may fail to meet design efficiency and/or discharge requirements because of (1) significant changes in the influent quality or quantity, (2) upsets in treatment processes resulting in the production of poor quality effluent and (3) power outages or equipment breakdowns that cause treatment processes to be bypassed.

SECONDARY TREATMENT


RAW WASTEWATER
PRELIMINARY TREATMENT
SCREENINGS AND GRIT TO LAND DISPOSAL
PRIMARY SEDIMENTATION
AERATION
SECONDARY SEDIMENTATION
CHLORINATION
TREATED EFFLUENT
RECYCLE SLUDGE
GRAVITY THICKEN
AIR FLOTATION THICKEN
SUPERNATANT
ANAEROBIC DIGESTION
SLUDGE DRYING BEDS
TO LAND DISPOSAL

ADVANCED WASTEWATER TREATMENT

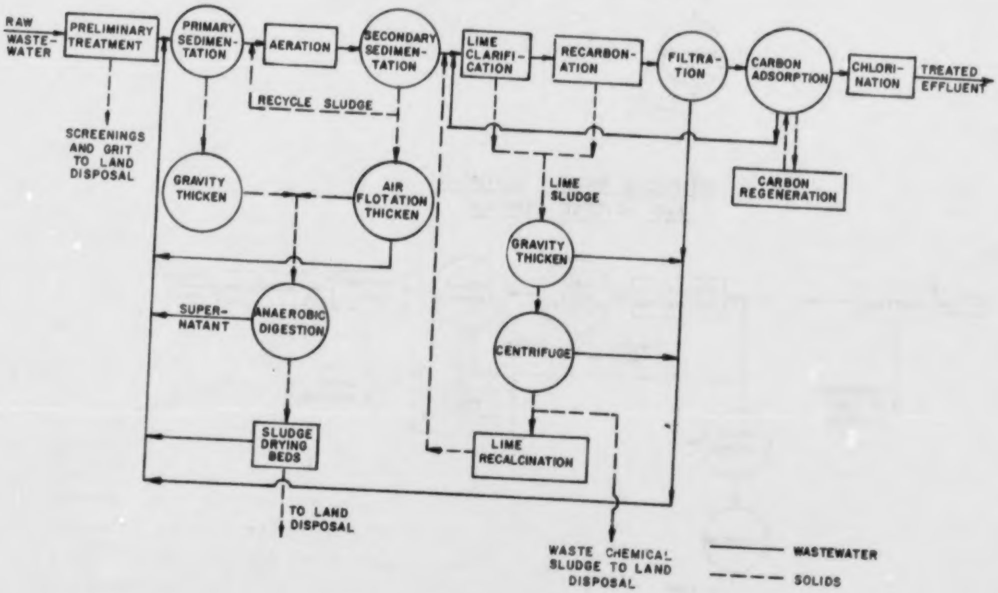
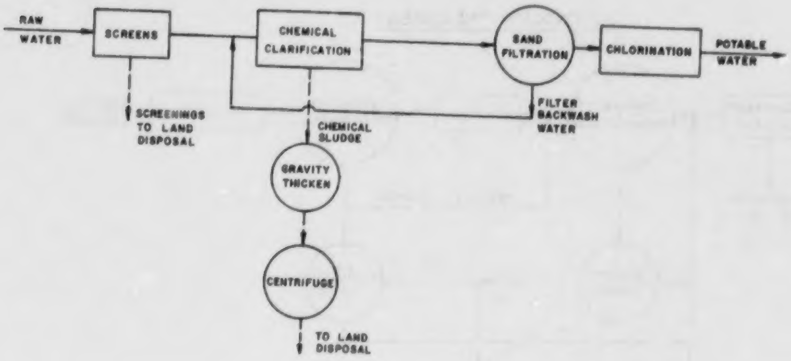
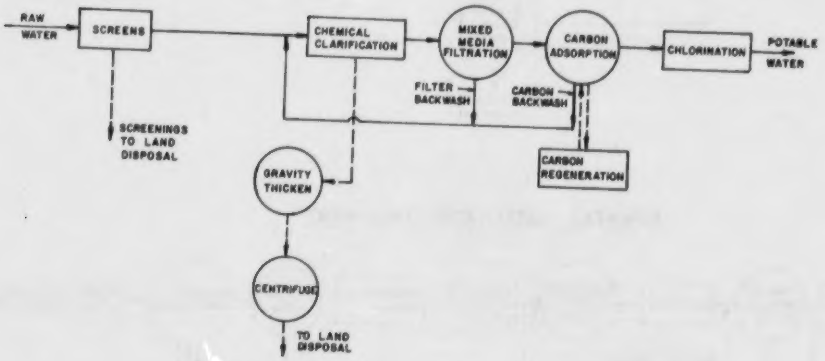

RAW WASTE-WATER
PRELIMINARY TREATMENT
SCREENINGS AND GRIT TO LAND DISPOSAL
PRIMARY SEDIMEN-TATION
AERATION
SECONDARY SEDIMEN-TATION
LIME CLARIFI-CATION
RECARBON-ATION
FILTRA-TION
CARBON ADSORPTION
CHLORI-NATION
TREATED EFFLUENT
RECYCLE SLUDGE
CARBON REGENERATION
GRAVITY THICKEN
AIR FLOTATION THICKEN
LIME SLUDGE
GRAVITY THICKEN
SUPER-NATANT
ANAEROBIC DIGESTION
CENTRIFUGE
SLUDGE DRYING BEDS
LIME RECALCINATION
TO LAND DISPOSAL
WASTE CHEMICAL SLUDGE TO LAND DISPOSAL
WASTEWATER
SOLIDS

Figure 2. WASTEWATER TREATMENT SYSTEMS

CONVENTIONAL WATER TREATMENT


RAW WATER
SCREENS
CHEMICAL CLARIFICATION
SAND FILTRATION
CHLORINATION
POTABLE WATER
SCREENINGS TO LAND DISPOSAL
CHEMICAL SLUDGE
FILTER BACKWASH WATER
GRAVITY THICKEN
CENTRIFUGE
TO LAND DISPOSAL

UPGRADED WATER TREATMENT


RAW WATER
SCREENS
CHEMICAL CLARIFICATION
MIXED MEDIA FILTRATION
CARBON ADSORPTION
CHLORINATION
POTABLE WATER
FILTER BACKWASH
CARBON BACKWASH
SCREENINGS TO LAND DISPOSAL
CARBON REGENERATION
GRAVITY THICKEN
CENTRIFUGE
TO LAND DISPOSAL

UPGRADED WATER TREATMENT
AND REVERSE OSMOSIS

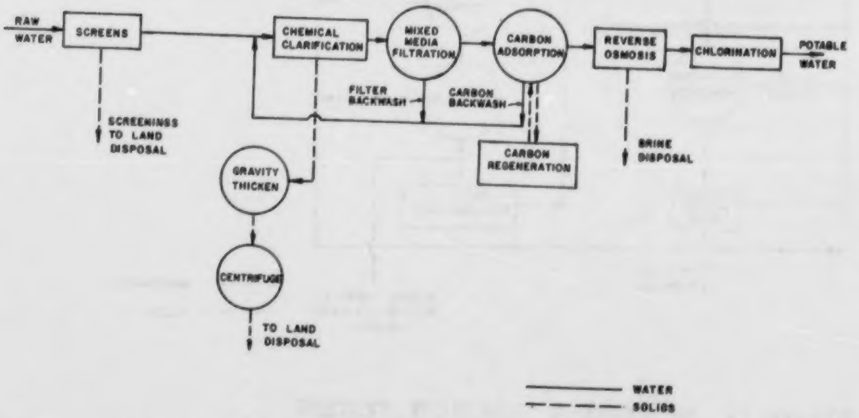

RAW WATER
SCREENS
CHEMICAL CLARIFICATION
MIXED MEDIA FILTRATION
CARBON ADSORPTION
REVERSE OSMOSIS
CHLORINATION
POTABLE WATER
FILTER BACKWASH
CARBON BACKWASH
SCREENINGS TO LAND DISPOSAL
CARBON REGENERATION
BRINE DISPOSAL
GRAVITY THICKEN
CENTRIFUGE
TO LAND DISPOSAL
WATER
SOLIDS

Figure 3. WATER TREATMENT SYSTEMS

TABLE 24

TYPICAL LEVELS OF ORGANIC CONSTITUENTS IN WATER AND WASTEWATER

	Concentration, mg/l			
	BOD	COD	TOC	Trihalomethanes
Stream Flow	5	30	10	ND
Effluents**				
Secondary	30	100	40	0.005
Direct Filtration	10	75	30	*
Chemical Clarification & Filtration	5	50	20	*
Advanced Wastewater Treatment	2	20	8	*
Conventional Water Treatment	<1	10	5	*
Upgraded Water Treatment	ND	2	1	*
Upgraded Water Treatment & Reverse Osmosis	ND	<1	<1	*

ND = None Detected

* Trihalomethane (chloroform) concentration depends on the point of chlorination. Chloroform concentrations are minimized by chlorinating the highest quality water.

** See text and Figures 2 and 3 for description of treatment systems.

The variability of effluent quality from wastewater treatment facilities was discussed by Ford[122] and he defined the term "inherant variability" as the effluent quality variability attributable to the basic nature of the unit process and the pattern of the raw waste loads. It is an unalterable characteristic of any treatment system. The raw waste load impact, process effects of water temperature and dissolved solids, and other process idiosyncrasies which cannot be altered to enhance overall stability are the primary factors responsible for inherant variability.

Section 210 of PL 92-500 requires the U.S. Environmental Protection Agency to conduct annual surveys and report to Congress on the efficiency of federally funded wastewater treatment facilities. The results of the surveys conducted in 1973, 1974 and 1975 were reported by Gilbert.[123] A major finding of the surveys was that about one third of the nation's municipal treatment facilities constructed with federal grant assistance were not operating at their designed efficiency level. These EPA surveys attempted to identify the causes of poor performance and concluded that the causes are many and varied and depend on several factors related to each specific treatment facility. The following summary shows data on trickling filter and activated sludge plants not meeting design criteria for BOD removal.

	Number and Percentage of Plants Not Meeting Design Criteria for BOD Removal			
	Activated Sludge		Trickling Filters	
Plant Capacity, mgd	No.	%	No.	%
0 - 1	99	22	102	42
1 - 5	39	23	100	42
5 - 15	23	37	32	65
over 15	16	67	3	20

The results of the performance efficiency surveys over the three year period revealed a continuing trend of significant deficiencies in a large number of municipal treatment facilities with respect to the actual performance compared with design criteria. Gilbert[123] concluded the following based on analysis of the surveys.

1. About one-third of the plants are not meeting original design criteria for removal of BOD.
2. About one-half of the plants are not meeting original design criteria for SS removal.
3. Activated sludge plants meet BOD and SS design removals more frequently than other process types; trickling filters have the poorest record.
4. The ability to evaluate plant operational performance is seriously affected by inadequate laboratory facilities and/or inadequate laboratory testing programs.

5. Plants with good maintenance management programs, as evidenced by adequate routine maintenance schedules, spare parts inventories, and records of maintenance repairs and replacement, perform better than plants with inadequacies in these areas.
6. Plants that are performing efficiently more often have operation and maintenance manuals written specifically for them than do plants that perform poorly.
7. Inadequate attention has been given to assuring routine attendance at short courses, schools, and other training programs for plant operations personnel. This problem occurs more frequently at those plants that do not have sufficient performance data to assess operational efficiencies.
8. The need for follow-up actions to correct operational, mechanical, or manpower deficiencies has remained high.

Performance data from trickling filter plants collected from EPA region inspection and technical assistance reports are summarized in Table 25. One to three years data were obtained from inspection of 13 trickling filter plants of various designs.[124] These data summarized in Table 26 indicate that in most cases, the trickling filter process does not produce effluent which will meet secondary treatment requirements as defined by EPA, i.e., effluent concentration of less than 30 mg/l for both BOD and SS, and a minimum of 85 percent removal for both parameters based on the plant influent concentration.

Activated sludge plant performance data from EPA region inspection and technical assistance reports are summarized in Table 27. These data are for conventional, contact stabilization and extended aeration variations of the activated sludge process. Daily data presented in the form of return frequency are shown on Figure 4 and were developed from nine activated sludge plants: four Austin, Texas contact stabilization plants and activated sludge plants at Grand Island, Nebraska; Dallas, Texas; High Point, North Carolina; Chicago, Illinois; and Ypsilanti, Michigan. The data in each case were from an entire year of operation. The plants selected for data presentation were those where good analyses are known to be performed, a variety of activated sludge processes are used and a range of loadings are experienced. The conclusions which may be made from these data are:

1. Two of the activated sludge plants treat significant industrial waste flows. The High Point, North Carolina, Eastside plant receives textile dye wastes and the Grand Island, Nebraska plant receives slaughterhouse wastes. Both plants perform as well as the other domestic waste plants. Therefore, activated sludge plants can be designed and operated to treat certain types of industrial wastes and perform as well as plants treating little or none of these industrial wastes.
2. The plant loadings range from 20 to 80 pounds of BOD per 1,000 cubic feet of aeration tank volume. The performance of the plants is not related to unit aeration basin organic loading.
3. Whereas all of the plants from which data are used are considered to have good operational control and design, the Grand Island plant, for one year, produced an effluent BOD significantly

TABLE 25. TRICKLING FILTER SUMMARY, EPA REGION DATA.

Location	Organic loading, lb BOD_5/ 1,000 cu ft	Flow, mgd		Influent, mg/l		Effluent, mg/l		Removal, %	
		Average	Design	BOD_5	TSS	BOD_5	TSS	BOD_5	TSS
Frederick, MD	High rate	4.6	7.0	351	161	100	40	72	76
Chapel Hill, NC	35	2.8	3.0	179	247	36	36	80	85
Marlboro, MA	74	2.22	2.0	134	112	62	32	54	71
Pichardson, TX	13	1.5	3.0	166	155	20	15	88	90
Allentown, PA	18	24.0	24.0	190	215	40	40	79	81
Pueblo, CO	42	14.6	14.0	148	163	39	29	74	82
Madera, CA	Del Pak	2.2	7.0	137	121	30	27	78	78
Mt. Vernon, CA	High rate	2.4	3.0	116	155	22	35	81	78
Santa Maria, CA	Two stage	4.4	6.5	200	280	33	45	84	84
Chinook, MT	High rate	0.22	0.5	168	179	71	59	58	67
Bountiful, UT	Std. rate	5.3	5.4	170	175	22	22	87	88
Englewood, CO	-	8.5	12.0	258	207	32	29	88	86
Murray, UT	-	4.9	8.0	193	193	36	35	81	82
Ft. Morgan, CO	Two stage	1.5	3.6	917	645	43	44	95	93
					Average removal			79	82

BOD_5 = 5-day Biochemical Oxygen Demand

TSS = Total Suspended Solids

TABLE 26. TRICKLING FILTER SUMMARY, PLANT VISITS

Location	Design flow, mgd	Average flow, mgd	Average effluent			
			BOD_5 mg/l	BOD_5 Removal, %	TSS, mg/l	TSS removal, %
Iowa:						
Shellsburg	0.0825	0.0609	47	70	-	-
Center Pt.	0.200	0.141	43	72	-	-
Monticello	0.800	0.412	39	80	-	-
Cascade	0.220	0.081	48	76	-	-
Independence	0.750	0.889	85	87	-	-
Lakeview	0.175	0.153	69	69	-	-
Georgia:						
Westside, 1975	1.00	1.059	25	75	30	70
Westside, 1976	1.00	0.971	35	72	38	68
Kennesaw, 1974	0.30	0.27	24	85	28	87
Sandtown, 1976	1.00	1.222	51	70	50	60
Newman, 1975	0.40	0.328	30	88	28	88
Newman, 1976	0.400	0.346	23	88	29	86
Intr. Cr., 1975	20.0	13.9	40	82	26	78
Intr. Cr., 1976	20.0	13.1	35	83	31	74
College Pk., 1976	1.2	1.36	43	90	35	76
Athens #1, 1975	5.00	5.60	80	69	64	73
Athens #1, 1976	5.00	5.14	64	73	47	80
Athens #2, 1975	2.00	2.90	46	73	58	68
Athens #2, 1976	2.00	2.60	47	75	40	78
Cedartown, 1974	1.00	0.82	46	77	40	80
Cedartown, 1975	1.00	0.92	17	89	18	90
Cedartown, 1976	1.00	1.06	23	88	22	88
	Average removal			79		78

TABLE 27. ACTIVATED SLUDGE SUMMARY, EPA REGION DATA

Location	Flow, mgd		Influent, mg/l		Effluent, mg/l		Removal, %	
	Ave	Design	BOD_5	TSS	BOD_5	TSS	BOD_5	TSS
CONVENTIONAL								
Aspen, CO	1.1	2.0	336	298	19	20	94	93
Missoula, MT	5.5	10.0	133	129	54	48	59	63
Snowmass, CO	0.8	0.8	185	180	34	53	82	71
Havre, MT	1.3	1.8	275	275	31	30	89	87
Barstow, CA	1.7	4.5	150	250	16	25	89	90
W. Sacramento, CA	3.5	2.5	140	130	20	27	86	79
Carmel, CA	2.5	3.0	200	300	20	30	90	90
Monterey, CA	3.5	4.6	250	250	35	70	86	72
Zephur Cove, NV	1.0	3.0	334	237	12	11	96	95
Fairfield, OH	1.3	1.0	173	172	26	26	85	85
Grand Rapids, ND	38	-	100	140	18	40	82	71
					Average removal		85	81
CONTACT STABILIZATION								
Richwood, WV	0.39	0.5	89	94	30	33	67	65
Pen Argyl, PA	1.1	0.95	162	75	16	26	90	62
Lolo, MT	0.15	0.25	233	172	17	12	93	93
Baden, PA	0.55	0.5	206	202	22	21	89	90
Lancaster, PA	9.24	12.0	168	227	32	35	81	85
Manteca, CA	1.3	3.2	200	180	50	25	75	86
Savage, MD	5.9	-	158	206	22	41	86	80
Coralville, IA	0.9	-	135	150	26	24	81	84
					Average removal		83	81
EXTENDED AERATION								
Athens, WV	0.15	0.25	129	258	14	33	88	84
Follansbee, WV	0.5	0.5	200	190	16	48	92	75
Cheyanne, WY	0.43	0.8	262	272	-	-	-	-
Elizabeth, CO	-	0.065	441	341	30	96	93	72
Elbert, CO	0.007	0.025	208	125	16	27	92	78
					Average removal		91	77

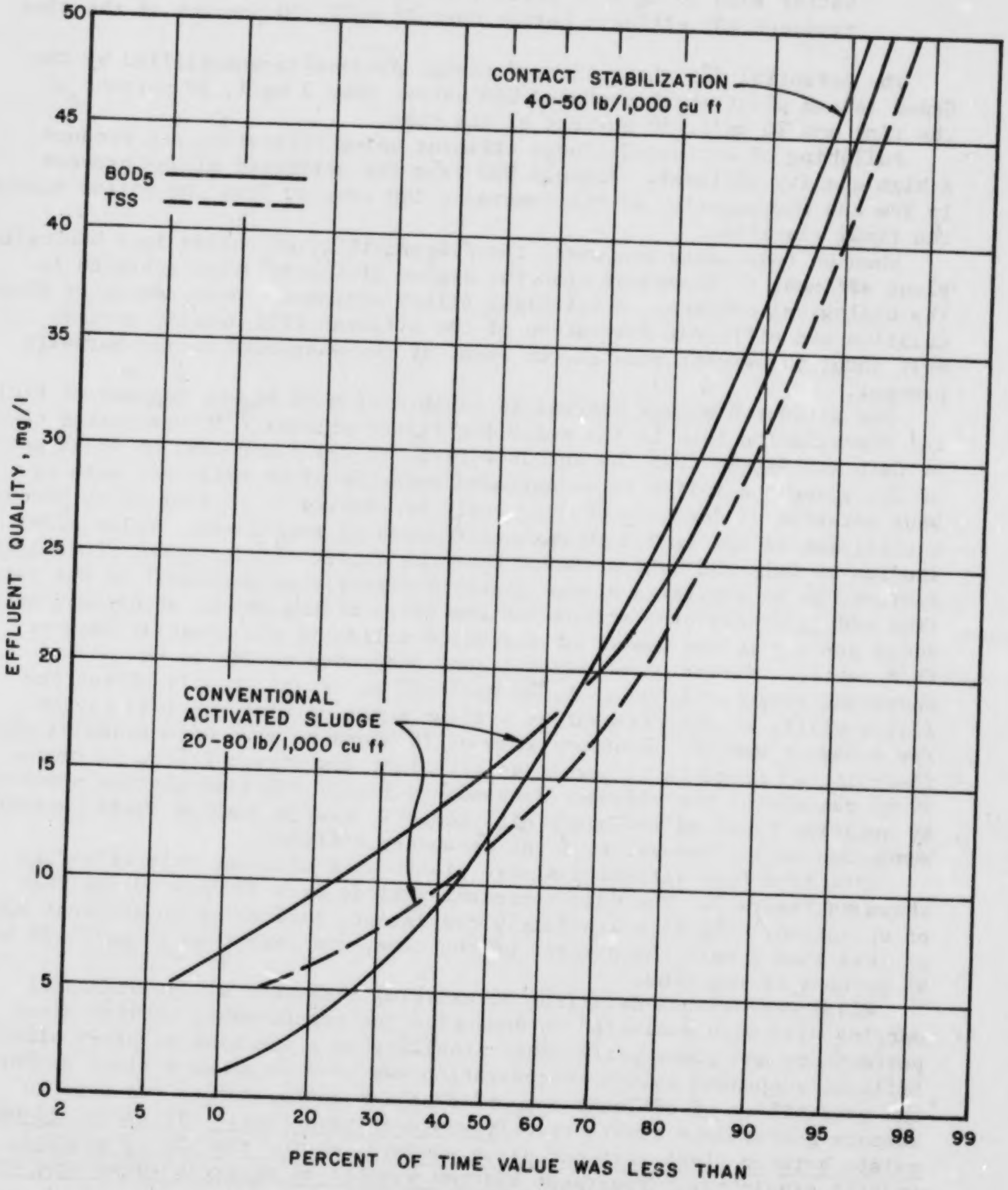


Figure 4. ACTIVATED SLUDGE EFFLUENT QUALITY

better than 10 mg/l 70 percent of the time. Four of the plants produced BOD effluent better than 35 mg/l, 90 percent of the time.

The potential for the activated sludge process is exemplified by the Grand Island plant which produced BOD better than 5 mg/l, 50 percent of the time and 20 mg/l, 90 percent of the time.

Polishing of activated sludge effluent using filtration can produce a high quality effluent. Soluble BOD from the activated sludge process is low and the majority of the remaining BOD results from the solids escaping the final clarifier.

When no coagulants are used, the filterability of solids in a biological plant effluent is dependent upon the degree of flocculation achieved in the biological process. A trickling filter achieves a poor degree of flocculation and efficient filtration of the effluent will usually provide only about 50 percent removal, or less, of the suspended solids normally present.

The activated sludge process is capable of much higher degrees of biological flocculation than is the trickling filter process. In unreported tests by Culp and Hansen from the author's firm, it was found that up to 98 percent of the suspended solids in an extended aeration plant effluent, with 24 hour aeration of domestic sewage, could be removed by filtration to produce turbidities as low as 0.3 TU without the use of coagulants. Pilot plant studies by Culp and Hansen showed that the degree of biological flocculation achieved in an activated sludge plant is directly proportional to the aeration time and inversely proportional to the ratio of the amount of organic material added per day to the amount of suspended solids in the aeration chamber (F/M ratio). Variation of mixed liquor suspended solids in the normal operating range of 1,500 to 5,000 mg/l did not significantly affect the filterability of the effluent at a given aeration time and load factor. For domestic wastes, aeration times of 10 hours or more were found to provide flocculation adequate to permit an efficient downstream filter to remove 90-98 percent of the effluent suspended solids. The flocculation provided by aeration times of 6-8 hours with domestic wastes enabled 70-85 percent suspended solids removal from the secondary effluent.

Data from four activated sludge plants with effluent filtration are shown in Figure 5. The data represent periods from 20 days to one year of operation. The data are fairly consistent, indicating an effluent BOD of less than 5 mg/l, 50 percent of the time, and less than 10 mg/l, 90 to 95 percent of the time.

Plant performance data from 30 existing activated sludge plants of varying size were evaluated to determine the relationship between plant performance and plant performance stability as a function of plant size.[125] Effluent suspended solids concentration was used to measure plant performance and variability of effluent suspended solids concentration was used to measure performance stability. It was concluded that: (1) no relationship exists between plant size and plant performance for the plants studied, and (2) single plant treatment systems exhibit no apparent advantages over multiplant treatment systems.

Daily data from one year of plant operation were studied for 28 activated sludge plants in the United States.[126] The average design flow of the plants varied from 0.6 to 333 mgd and the median flow was 28 mgd. Based on an

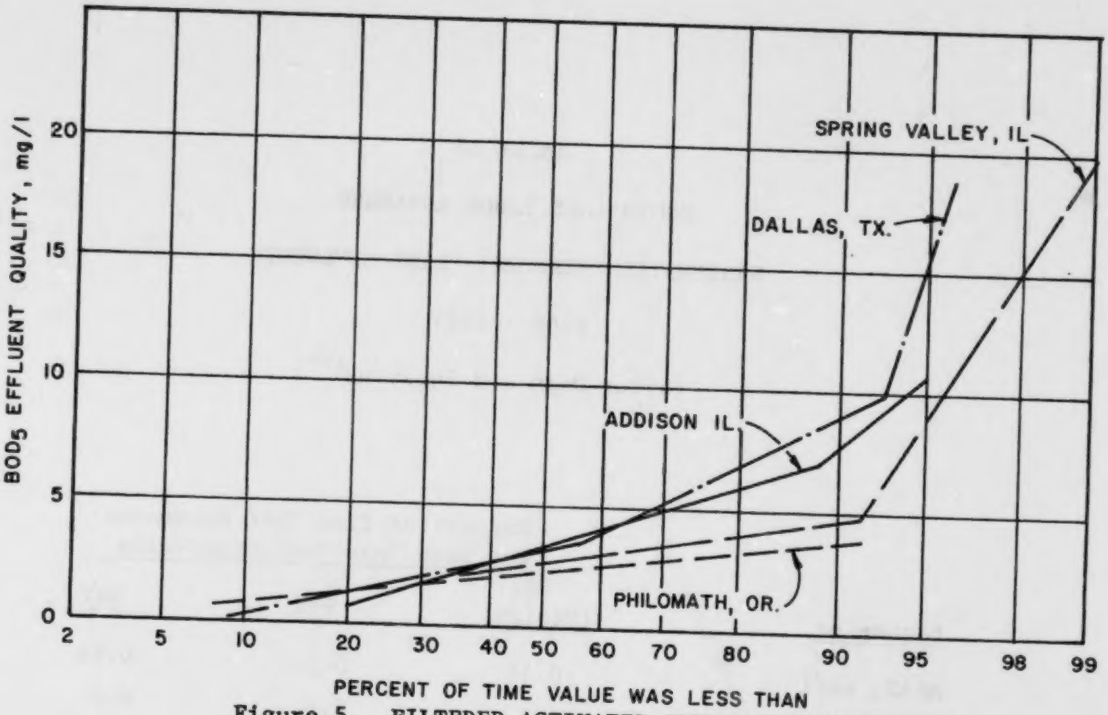


Figure 5. FILTERED ACTIVATED SLUDGE EFFLUENT BOD

analysis of BOD and suspended solids data, it was concluded that (1) treatment efficiency decreased with increasing design capacity, and (2) the optimum size treatment plant could not be determined from the data analyses.

Six years of daily operating data (1968-74) at the South Lake Tahoe AWT plant were statistically analyzed[127] and the results are summarized in Table 28. The data analysis included calculation of correlations between pairs of parameters. No significant correlation between parameters was found and it was concluded that random fluctuation account for most of the variations in the data including: errors in sampling, recording and analytical procedures as well as process changes that primarily influence a single variable. It was also concluded that: (1) the plant was obviously operated under good control, and (2) to improve the reliability of a plant like South Lake Tahoe, it would be necessary to alter the design. The variability in performance is much less than for secondary treatment plants and, of course, the overall level of performance is much better.

Federal guidelines published in 1970 identify eight design provisions and four other significant factors related to treatment plant reliability.[128]

Design Factors

Duplicate power sources
Stand-by power
Multiple units and equipment
Emergency storage
Piping and pumping flexibility

Other Factors

Engineering report
Qualified personnel
Effective monitoring program
Effective maintenance and process control program

TABLE 28

SOUTH LAKE TAHOE ADVANCED WASTEWATER TREATMENT PLANT EFFLUENT

1968 - 1974

(after Dean and Forsythe[127])

	Percent of Time That Parameter Was Less Than Indicated Value		
Parameter	50% (Median)	98%	99%
MBAS, mg/l	0.18	0.54	0.64
BOD, mg/l	1.3	5.4	6.4
COD, mg/l	9.6	24.5	30.7
Suspended Solids	0	0	0
Turbidity, JTU	0.3	1.2	1.5
Phosphorus, mg/l	0.19	0.91	1.22
Chlorine Residual, mg/l	0.90	3.0	3.6
Coliform, MPN/100 ml	(0.025)	5.1	13.0

Design Factors (Cont'd)
Dual chlorination
Automatic chlorine residual control
Automatic alarms

The California State Department of Public Health conducted a study of wastewater treatment plants operating in California during 1964. This study and other performance data collected by the Health Department revealed a lack of reliability in many wastewater treatment plants.[129] Subsequently, the State of California developed wastewater treatment reliability criteria,[130] that are now State law.[131] The law applies to wastewater treatment plants that produce effluent for reuse and contains specific reliability requirements for design and operation. These requirements are contained in Appendix A.

Reliability considerations were a major factor in the policy adopted by the State of Virginia concerning the design of wastewater treatment facilities that discharge to raw drinking water supplies.[132] Major design factors in this policy for a specific project (This is the Occoquan project and is described in Section 8 of this report on case studies.) proposed to discharge treated wastewater to a raw water supply serving 500,000 people include the following:

- The initial backup capacity within the plant shall be 100 percent for the initial increments of the plant. If after the initial few years of operation, the plant's reliability has been satisfactorily demonstrated, additional treatment trains can be added up to a ratio of four treatment units or one stand-by train.
- The design shall be such that expansions and maintenance of any unit can be accomplished without by-passing wastes or degrading treatment.
- The mechanical and fluid system design shall be such that a single failure of a component or unit shall not interrupt plant operations which are required to meet the final effluent requirements.
- There shall be two sources of outside power and one on-site power supply. Both the off-site and on-site electrical distributions shall be such that the failure of any given components (mechanical or electrical) in the distribution system shall not cause an interruption of electrical service to parts of the plant which are essential to meet the effluent requirements.
- Retention basins to handle an unpredictable set of events which might temporarily overload the plant and to provide a margin of safety in the event of operator error. The total required retention capacity can be provided at the treatment plant proper or on the interceptor system some distance away from the plant, depending on the availability of land. However, at least one-day capacity should be available at the plant.
- Backup capacity of 100 percent for raw waste pumps.
- Duplicate treatment facilities for primary and secondary treatment, chemical clarification units and chlorination. Adequate backup facilities for filtration and activated carbon contactors.

- A sampling basin to determine water quality before release. Effluent not meeting the required quality to be returned to the plant for treatment by the AWT processes.

- Continuous operator attendance with at least five people per shift (initial plant capacity is 10.9 mgd).

- Failure mode and effects analysis on mechanical and electrical systems.

The design factors developed by the State of Virginia go beyond the reliability features of the South Lake Tahoe plant and would provide a superior degree of reliability; but, the added features will increase costs.

This review of treatment plant performance indicates that it is possible to routinely achieve the average results shown in Table 24 for activated sludge secondary treatment and AWT. The cost effects of providing essentially 100 percent reliable treatment processes are discussed in the following Section 7 on alternative treatment systems.

HEALTH CONSIDERATIONS

It is well understood among public health workers that domestic sewage contains agents of human disease. Thus the location of drinking water intakes downstream from the discharge of wastewater, treated or untreated, is of concern to health authorities because of the potential for disease transmission.

In considering the transmission of disease one must take the following factors into account: (1) the presence of agents of disease, (2) the concentration of the agent or the dose, (3) the dose response, and (4) the host contact.

The agents of disease present in domestic wastewater may most conveniently be divided into two large groups. One group includes those agents of an infectious nature and the other the chemical or non-infectious toxins.

Biological Agents

A number of bacterial diseases have been associated with the consumption of sewage contaminated water including typhoid fever, salmonellosis, shigellosis, cholera, and infections due to enterocytopathic *Escherichia coli* and *Yersina entercolitica*. During the 13 year period 1969-74 the majority of waterborne outbreaks of bacterial disease in the United States were due to *Shiegella* sp. followed by *Salmonella* sp., typhoid fever and pathogenic *Escherichia coli*. Less than 10 percent of the cases of these diseases in the United States were waterborne.[133]

The two waterborne parasitical diseases commonly associated with contaminated water are amoebic dysentary and giardiasis, both protozoan diseases. Less than 1.5 percent of waterborne disease outbreaks are due to these parasites.

There are at least 101 types of viruses that may find their way into water via fecal contamination. Of these the most serious threat to the public health (in terms of disease severity) is the virus of infectious hepatitis (Hepatitis A). Less than one percent of the reported cases of hepatitis in the United States are attributable to contaminated drinking water. A large proportion of cases were associated with the consumption of contaminated shellfish.

The low incidence of infectious disease transmission via finished drinking water is a testimony to present drinking water sanitation technology. However, the potential presence of these agents in waters receiving waste discharge must be assumed and may therefore be found at the intake of downstream water treatment plants.

Chemical Agents

Chemical agents of disease, either actual or potential, found in water and wastewater are most conveniently divided into inorganic and organic categories. The chemicals of an inorganic nature that impact upon health are the best understood because of a long history of recognizing their health importance and well developed analytical technology. Even so, there are still many gaps in understanding the health implications of the consumption of some of these compounds present in water. This is particularly so when chronic disease is involved, as for example, the case of the observed statistical association between water hardness and heart disease. The inorganic chemicals that appear to be most important to health are those for which MCLs have been established in the Primary Drinking Water Regulations.

For many years a number of specific organic compounds, particularly chlorinated hydrocarbons, have been recognized as hazardous in drinking water and have been listed in U.S. drinking water standards. During the last few years increased interest and activity has taken place concerning the occurrance of trace organic chemicals in U.S. drinking water supplies. More than 700 such compounds have been identified from various water supplies. One of the most prevalent groups of compounds present in finished drinking water is the trihalomethanes and particularly chloroform.

This latter arises as the result of the chemical interaction of chlorine with organic precursors such as humic substance, many of which are naturally present in water. There are many questions concerning the human health effects, if any, produced by the presence of these compounds in drinking water particularly in reference to the cancer morbidity of exposed populations. Known and suspected carcinogens reportedly found in finished water are listed in Table 29. The list is not exhaustive particularly as regards suspected animal carcinogens. Perhaps the brominated trihalomethane, bromoform, should be included under the suspended animal carcinogen category.

Identification and Dose

The second factor to consider in the transmission of disease via water is the concentration of disease agent present. If the nature of an agent is sufficiently understood then methods can be developed to quantitatively determine its presence in water. In certain instances because of the technical difficulty in measuring an agent or agents it may be possible to monitor a surrogate parameter rather than the actual agents. This is particularly true when a large variety of agents may be present and the measurement of each would present a monumental task.

TABLE 29

CATEGORIES OF KNOWN OR SUSPECTED ORGANIC CHEMICAL CARCINOGENS FOUND IN DRINKING WATER

(from reference 1)

Compound	Highest Observed Concentrations In Finished Water µg/l
Human Carcinogen	
Vinyl Chloride*	10
Suspected Human Carcinogens	
Benzene	10
Benzo (a) pyrene*	D
Animal Carcinogens	
Dieldrin	8
Heptachlor	D
Chlordane	0.1
DDT/DDE	D
Lindate (γ-BHC)	0.01
α-BHC	D
β-BHC	D
PCB (Aroclor 1260)	3
Chloroform	336
Carbontetrachloride	5
Trichloroethylene	0.5
Diphenylhydrazine	1
Aldrin	D
Suspected Animal Carcinogens	
Bix (2-chloroethyl) ether	0.42
Endrin	0.08
Heptachlor epoxide	D

* Also an animal carcinogen
D = Detected but not quantified

Infectious disease agents have traditionally been monitored in water using a surrogate parameter, the coliform-fecal coliform test. The presence of these bacteria in water is indicative of the presence of fecal material and thus the potential presence of pathogenic enteric organism. Through the years this test has been effectively used in the quality control of finished drinking water. More recently some shadow of doubt has been cast upon the efficiency of the coliform test. As there is evidence that certain of the enteric viruses are more resistant to chlorination than are the coliform bacteria. Thus the absence of the latter organisms in finished drinking water may not guarantee the absence of enteric viruses. However, epidemiologically there is very little evidence that coliform standards for drinking water have been ineffective in protecting the public from infectious disease including that of viral origin.

To date no simple method has been devised to routinely test for the presence of animal viruses in drinking water.

The determination of the dose of inorganic chemical agents for the most part is relatively straight forward analytical water chemistry. Many of these agents have been recognized for years and suitable detection methods developed. The identification and quantification of small concentrations of organic compounds in water can be relatively straight forward for certain well established compounds such as many of the chlorinated hydrocarbon pesticides. However, the identification and quantification of the myriad organic compounds that might be present can be extremely complicated, time consuming and in many cases, with the present state of the art, impossible. This is a situation wherein a surrogate parameter would prove extremely useful. Unfortunately no such parameter exists at present.

Measuring the presence of various organic compounds in water may be very difficult, but an even more difficult task, is to establish whether or not such compounds are also toxic to humans. At present most estimates of the disease potential of these materials are based on long term laboratory studies with animals and extrapolating the results to men, or are based upon epidemiological evidence, usually gained in the occupational setting, that an association exists between exposure to a given chemical and human disease. The carcinogenic properties of organic compounds are of great concern but are difficult to determine.

A promising test for measuring the mutagenic potential of chemicals (or unknown mixtures such as wastewater using special bacterial strains) has been developed by Ames and his co-workers.[134] This test system appears to be relatively simple, quite sensitive to most known carcinogens and results are obtained fairly rapidly. This type of test will prove valuable in screening for the presence of material with mutagenic/carcinogenic properties. However, there will still be the problem of associating such information with the incidence of human disease in the exposed community, i.e., although these substances cause increased mutations in microorganisms will they be mutagenic in man?

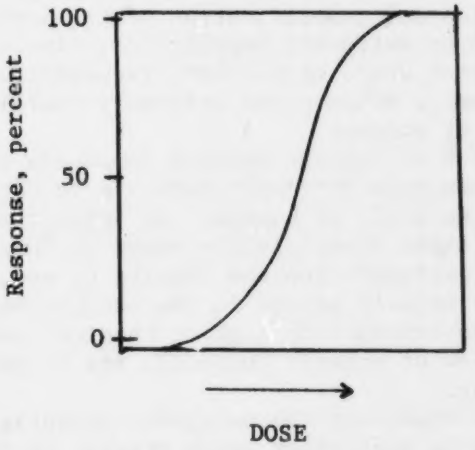
Host Contact

The manner in which the exposed population comes into contact with a disease agent is a most important factor in evaluating the health risk from such exposure. In the case of drinking water the exposure via ingestion is mot intimate and implies a greater risk to the population than would a less personal exposure such as might occur while boating or fishing. Thus, in considering the public health implications of the siting of drinking water intake below wastewater discharges, it must be assumed that the host contact with any agent that might be present is a critical one.

Dose Response

The last criterion to be examined is dose response, i.e. what concentration of agent is required to bring about illness in the exposed population. This is one of the most important aspects in considering the impact of wastewater discharge upstream from community drinking water intakes. What concentrations of agents can be present and not unduly affect the consumer? How will the treatment of wastewater, the hydraulic characteristics of the intervening water course, and the treatment of the drinking water prior to distribution affect the concentration of disease agents present in the finished drinking water?

The most fundamental concept in toxicology is the dose response relationship. The following figure is a generalized dose response curve.



This curve assumes a normal distribution in the frequency of response and indicates that there is some level of dose at which there is no measureable response, or a threshold concentration.

Ideally the concentration of disease agents present in drinking water delivered to the consumer should be below the threshold dose. Unfortunately, the dose response characteristics of the disease agents that might be present in water are frequently now known, and, in the case of carcinogenic agents, there is disagreement as to whether a threshold concentration exists. Because of this lack of understanding, public health authorities have traditionally relied upon elimination of the agent by use of that treatment method that appears to give the greatest reduction in agent concentration or by reducing contact of susceptibles with the suspect material by prohibiting its use. With increasing pressure for more contact with these materials, and recognition that total elimination of various disease agents is impossible or impractical, the assessment of the risk of disease in exposure to various concentrations of these agents is essential.

Some information exists concerning the dose response relationships between humans and certain bacterial and parasitical diseases. There is a notable deficiency in dose response data involving enteric viruses. In the case of bacteria and certain parasites, it is evident that there is a threshold dose below which few cases of clinical disease occur. In order to illicit a response in 25 to 75 percent of humans challenged, it required 1 x 10^2 to 1 x 10^3 shigella; 1 x 10^6 to 1 x 10^9 salmonella; 1 x 10^4 to 1 x 10^7 typhoid bacilli; 1 x 10^6 to 1 x 10^{10} *Escherichia coli*; and, 1 x 10^3 to 1 x 10^8 cholera vibrios, per dose.[135]

The two enteric pathogens *Entamoeba histolytica* (amoebic dysentary) and *Giardia sp*. evidence similar dose response relationships. It should be pointed out that, in a number of instances, infections without clinical diseases were recorded at lower exposure doses. As stated previously, data for enteric virus dose response is not well established. There are proponents that feel that one unit of virus is an infective dose and others who feel that a threshold dose exist.

The dose of infectious agents present in water is routinely measured using the coliform and fecal coliform index and there is little epidemiological evidence to suggest that the procedures is ineffective, i.e., when coliform levels that meet presently established drinking water standards are met, enteric infectious disease transmission is low. Thus, any combination of detection and treatment which meets these coliform levels will protect the population from disease, including enteric viruses, to a degree accepted by present day health jurisdictions.

The public health implications of trace amounts of many of the organic compounds found in water is uncertain at the present time. The uncertainty is the result of several factors: (1) the chronic nature of disease suspected to be associated with these chemicals (such as cancer), (2) health risk data is usually generated using animals receiving relatively high doses of suspect compounds, (3) health risk data must be extrapolated to estimate dose response to much lower concentrations, and (4) the extrapolated health risk data must be further extrapolated from animal to man.

The National Academy of Sciences report[1] deals in part with the question of toxic organic chemicals in water and their dose response. The list of pesticides and other toxic chemicals in water presented in Table 30 is from the NAS report. The table shows estimates of the acceptable daily intake (ADI) of these compounds based upon available human and animal data. It should be noted that 27 of the 39 ADI values listed were treated with an uncertainty factor of 1000 and only four with a factor of 10 which illustrates the doubt involved in making human dose response predictions. However, this data can be used to give a first estimate for allowable concentrations in drinking water. This list of compounds in Table 30 is quite incomplete as there are many more organic chemicals for which either there is no information available or the information is so limited that no estimates of dose response can be made.

The evaluation of the impact upon the morbidity of cancer in populations exposed to low concentrations of known or suspected carcinogens present in drinking water is subject to the same difficulties and uncertainties noted above for toxic organic chemicals. Added to the problem is the question as

TABLE 30

ORGANIC CONTAMINANTS IN DRINKING WATER CONCENTRATIONS TOXICITY, ADI AND SUGGESTED NO ADVERSE EFFECT LEVELS

(from reference 1)

Compound	Maximum Observed Concentrations In Water (micorgram per liter)	Maximum Dose Producing No Observed Adverse Effect (milligram per kilogram per day)	Uncertainty Factor(1)	ADI(2) (milligram per kilogram per day)	Suggested No Adverse Effect Level From Water, Microgram per Liter Assumptions(3) 1	2
2, 4-D	0.04	12.5	1,000	0.0125	87.5	4.4
2, 4, 5-T		10.0	100	0.1	700	35
TCDD		10^5	100	10^7	7×10^4	3.5×10^5
2, 4, 5-TP	(4)	0.75	1,000	0.00075	5.25	0.26
MCPA		1.25	1,000	0.00125	8.75	0.44
Amiben		250	1,000	0.25	1,750	87.5
Dicamba		1.25	1,000	0.001125	8.75	0.44
Alachlor	2.9	100	1,000	0.1	700	35
Butachlor	0.06	10	1,000	0.01	70	3.5
Propachlor		100	1,000	0.1	700	35
Propanil		20	1,000	0.02	140	7
Aldicarb		0.1	100	0.001	7	0.35
Bromacil		12.5	1,000	0.0125	87.5	4.4
Paraquat		8.5	1,000	0.0085	59.5	2.98
Trifluralin (also for Nitralin and Benefin)	(5)	10	100	0.1	700	35
Methoxychlor		10	100	0.1	700	35
Toxaphene		1.25	1,000	0.00125	8.75	0.44
Azinphosmethyl		0.125	10	0.0125	87.5	4.4
Diazinon		0.02	10	0.002	14	0.7
Phorate (also for Disulfoton).		0.01	100	0.0001	0.7	0.035
Carbaryl		8.2	100	0.082	574	28.7
Ziram (and ferbam)		12.5	1,000	0.0125	87.5	--
Captan		50	1,000	0.05	350	17.5
Folpet		160	1,000	0.16	1,120	56
HCB	6	1	1,000	0.001	7	0.35
PDB	1	13.4	1,000	0.0134	93.8	4.7
Parathion (and methyl parathion)		0.43	10	0.0043	30	1.5
Malathion		0.2	10	0.02	140	7
Maneb (and zineb)		5	1,000	0.005	35	1.75
Thiram		5	1,000	0.005	35	1.75
Atrazine	5.0	21.5	1,000	0.215	150	7.5
Propazine	(5)	46.4	1,000	0.464	325	16
Simazine	(5)	215	1,000	0.215	1,505	75.25
Di-n-butyl phthalate . .	5	110	1,000	0.11	770	38.5
Di (2-ehtyl hexyl) phthalate	30	60	100	0.6	4,200	210
Hexachlorophene	0.01	1	1,000	0.001	7	0.35
Methyl methacrylate . . .	1	100	1,000	0.1	700	35
Pentachlorophenal	1.4	3	1,000	0.003	21	1.05
Styrene	1	133	1,000	0.133	931	46.5

---

(1) Uncertainty Factor - the factor of 10 was used where good chronic human exposure data was available and supported by chronic oral toxicity data in other species, the factor of 100 was used where good chronic oral toxicity data were available in some animal species, and the factor of 1,000 was used with limited chronic toxicity data or when the only data available were from inhalation studies.

(2) Acceptable Daily Intake (ADI) - maximum dose producing no observed advaerse effect divided by the uncertainty factor.

(3) Assumptions: Average weight of human adult = 70 kg; Average daily intake of water for man = 2 liters; 1.20 pct of total ADI assigned to water, 80 pct from other sources; 2.1 pct of total ADI assigned to water, 99 pct from other sources.

(4) Detected but not quantified.

(5) Detected

to whether or not the concept of threshold dose is valid. This question arises because of: (1) the self replicating nature of the cancer cell, (2) the probability that the tumor causing event is irreversible, and (3) the possible occurance of cancer long after the disappearance of the carcinogen from the body.[136]

In a recent article Stokinger[137] stated the belief that threshold concentrations do exist for carcinogenic compounds and that drinking water standards should be developed from that point of view. Most of the supporting data is taken from industrial exposures and animal experimentation. Stokinger concludes that toxic response is frequently much different at low concentration of toxic chemicals and therefore extrapolation from "high" dose experiments to estimate "low" dose response is invalid.

Others such as Mantel and Bryan[138] believe that a no response dose of carcinogen may not exist; rather, there is some risk of contracting disease regardless of dose and that risk increases with increased exposure, i.e., is dose related. Such risks are determined using a variety of statistical methods. Mantel and Bryan suggest extrapolation from high dose response data to an appropriate risk level using a probit slope of 1 to 1.5 probit per 10 fold increase in dose. This assumes that response frequency is normally distributed. Probits are calculated as standard deviations about the mean of normal distribution giving zero deviation (the 50 percent response point) a value of 5. This method is commonly used and is considered to give conservative values because it does not include: (1) the probabilities that the individual involved will be overshadowed by some competing health risk, (2) the probability that an individual will receive a given exposure, and (3) the age of the individual when the cancer will occur.

The approach taken by the National Academy of Sciences[1] in the assessment of human health risks from exposure to environmental chemicals is explained in the following four principles:

> *Principle 1 - Effects in animals, properly qualified, are applicable to man. This premise underlies all of experimental biology and medicine. But, because it is continually questioned with regard to human cancer, it is desirable to point out that cancer in men and animals is strikingly similar. Virtually every form of human cancer has an experimental counterpart; and every form of multicellular organism is subject to cancer, including insects, fish, and plants. Although there are differences in susceptibility between different animal species, and between individuals of the same strain, carcinogenic chemicals will affect most test species; also large bodies of experimental data indicate that many chemicals that are carcinogenic to animals are likely to be carcinogenic to man, and vice versa...*
>
> *Principle 2 - Methods do not now exist to establish a threshold for long term effects of toxic agents. With respect to carcinogenesis, it seems plausible at first thought, and it has often been argued, that a threshold must exist, below which even the most toxic substance would be harmless. Unfortunately, a threshold cannot be established experimentally that can be applied to a total population. A time-honored practice of classical toxicology is to establish maximal tolerated (no-effect) doses in humans on the basis of finding a*

no-observed-adverse-effect dose in chronic experiments in animals and to divide this dose by a "safety factor" of say, 100, to designate a "safe" dose in humans. There is no scientific basis for such estimations of safe doses in connection with carcinogenic effects....

Experimental biossays in which even relatively large numbers of animals are used are likely to detect only strong carcinogens. Even when negative results are obtained in such biossays, it is not certain that the agent tested is unequivocally safe for man. Therefore, we must accept and use possibly fallible measures of estimating hazard to man....

Principle 3 - The exposure of experimental animals to toxic agents in high doses is a necessary and valid method of discovering possible carcinogenic hazard in man. The most commonly expressed objection to regulatory decisions based on carcinogenesis observed in animal experiments is that the high dosages to which animals are exposed have no relevance in assessment of human risks. It is therefore important to clarify this crucial issue.

Practical considerations in the design of experimental model systems require that the number of animals used in experiments on long-term exposure to toxic materials will always be small compared with the size of the human population similarly at risk. To obtain statistically valid results from such small groups of animals requires the use of relatively large doses so that the effect will occur frequently enough to be detected. For example, an incidence as low as 0.01 percent would represent 20,000 people in a population of 200 million and would be considered unacceptably high, even if benefits were sizable. To detect such a low incidence in experimental animals directly would require hundreds of thousands of animals. For this reason, we have no choice but to give large doses to relatively small experimental groups and then to use biologically "reasonable" models in extrapolating the results to estimate risk at low doses. Several methods for making such calculations have been considered and used, but we think that the best method available to use today is to assume that there is no threshold and that a direct proportionality exists between the size of the dose and the incidence of tumors. However, it is important to recognize that such a calculation may give either too small or too large an estimate of risk. The actual risk to humans might be even greater over a human lifetime, because it is about 35 times that of a mouse; and there is evidence that the risk of cancer increases rapidly with the length of exposure. Moreover, experimental assays are conducted under controlled dietary and environmental conditions with genetically homogeneous animals, whereas humans live under diverse conditions, are genetically heterogeneous, and are likely to include subpopulations of unusual susceptibility....

Principle 4 - Material should be assessed in terms of human risk, rather than as "safe" or "unsafe". The limitations of the current experimental techniques do not allow us to establish safe doses, but with the help of statistical methods we may be able to estimate

> *an upper limit of the risk to human populations. To calculate such a risk, we need data to estimate population exposure; a valid, accurate, precise, and reproducible assay procedures in animals; and appropriate statistical methods....*
>
> *Most of the toxicological information on chemicals has been accumulated from studies conducted on animals in high dose rate test conditions. Some epidemiological information from human exposure has also been gathered, usually from occupational exposures, but these cannot be relied upon as the primary means of assessing human risks. Some recent preliminary epidemiological studies imply a possible relationship between some drinking water variables and the risk of certain types of cancer in the population. The tragedy of identifying actual cases of cancer (and deaths) attributable to specific chemical exposure demonstrates that sufficient testing in animals had not been conducted in advance to determine risks prior to human exposure.*

The risk of developing cancer during a lifetime of exposure (70 years) to known or suspected carcinogens listed in Table 29 that might be found in water was reported by the National Academy of Sciences.[1] The following values were determined using a mathematical risk model which estimates that increment of risk of disease due to consumption of suspect compounds in water.

Compound	Upper 95% Confidence Estimate of Lifetime Cancer Risk per μg/l
Vinyl Chloride	5.1×10^7
Dieldrin	2.6×10^4
Heptachlor	4.2×10^5
DDT/DDE	1.2×10^5
Lindane	9.3×10^6
Chloroform	3.7×10^7
Trichloroethylene	1.3×10^7

Thus, based upon these calculations, there would be one excess death from cancer per 37 million people who drink water containing 1 mg/l of chloroform. If these are accurate estimates, then as the level of compound increased to 100 mg/l it could mean an increase of about 600 excess deaths among the 220 million people in the United States due to chloroform in drinking water.

Tardiff estimated the cancer risk from the daily consumption of 0.01 mg of chloroform per pound of body weight using a variety of risk models including probit log, linear and two step methods.[139] A dose of 100 mg chloroform per liter per day to a 22 pound infant would be equivalent to 0.01 mg/kg which, from human data, should not cause any liver damage. Using such models it was calculated that the incidence of cancer could be increased by 1.6 per million population per year, or, of the approximately 300,000 cancer deaths annually, in the United States, 252 might be attributable to chloroform in tap water. Tardiff concludes that the risk lies somewhere between zero and 252 at a chloroform concentration of 100 mg/l.

SECTION 7

ALTERNATIVES IN WATER INTAKE LOCATIONS

The location of a water intake downstream of a wastewater discharge is an integral part of the overall wastewater discharge-water treatment system and various combinations of wastewater treatment, storage, effluent discharge, stream flow, water intake and water treatment may be used. The purpose of this section is to consider some of these combinations by evaluating the performance of several alternatives, or cases, in terms of expected water quality, costs and reliability.

A schematic diagram of the overall wastewater discharge-water intake system is shown in Figure 6. This overall system includes the following:

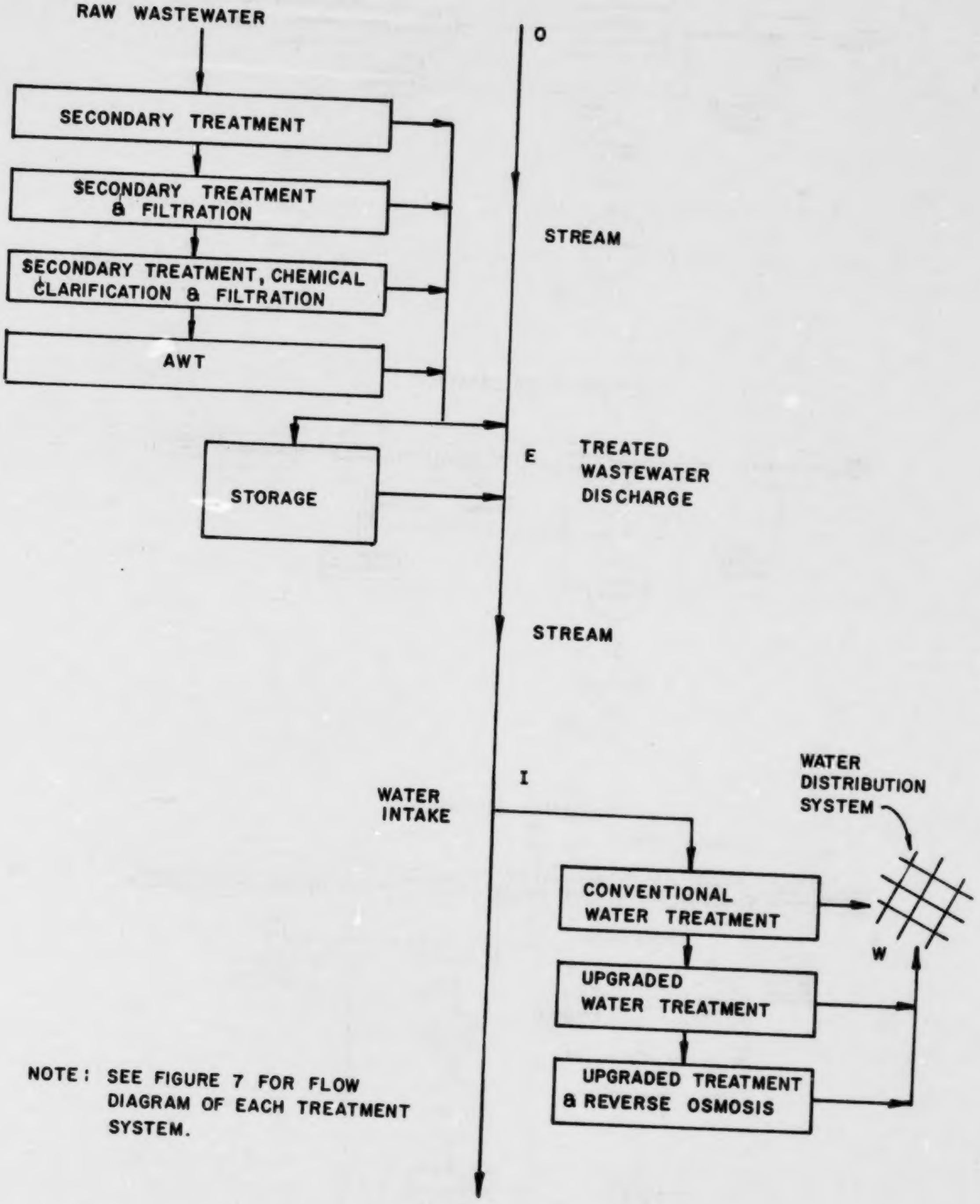
1. River flow above the wastewater discharge (point O).
2. Wastewater discharge (point E). Wastewater is treated with a minimum of secondary treatment before discharge. Additional treatment and storage may also be provided before discharge. Separation time between wastewater discharge and water intake may be achieved in a storage basin or in the stream itself.
3. Flow of blended stream water-wastewater to the water intake (point I).
4. Water is withdrawn from the stream and treated with a minimum of conventional treatment and discharged to the distribution system (point W).

ALTERNATIVE TREATMENT SYSTEMS

Flow diagrams for alternative water and wastewater treatment systems shown in Figure 7 include the following:

Secondary Treatment (ST) - Aerated grit removal, primary sedimentation, mechanical aeration, secondary sedimentation, chlorination, gravity thickening of primary sludge, air flotation thickening of waste activated sludge, anaerobic digestion, sludge drying beds and land disposal.

Advanced Wastewater Treatment (AWT) - Secondary treatment followed by lime clarification and two-stage recarbonation, mixed-media filtration, upflow granular carbon adsorption with on-site carbon regeneration, chlorination, gravity thickening of lime sludge, centrifugation, lime recalcination and land disposal of primary, secondary and waste lime sludges.

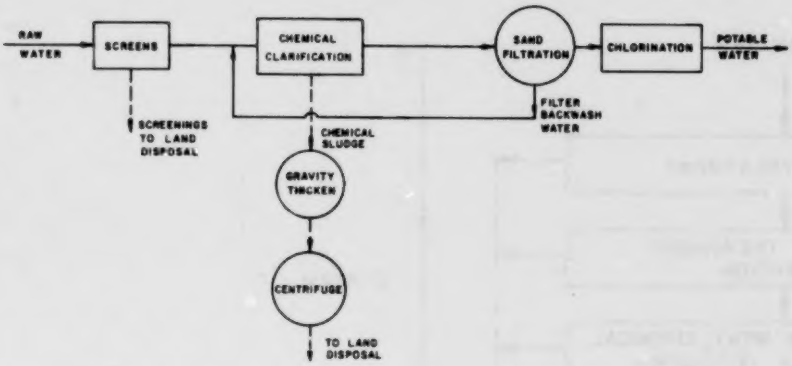


RAW WASTEWATER
SECONDARY TREATMENT
SECONDARY TREATMENT & FILTRATION
SECONDARY TREATMENT, CHEMICAL CLARIFICATION & FILTRATION
AWT
STORAGE
O
STREAM
E
TREATED WASTEWATER DISCHARGE
STREAM
I
WATER INTAKE
WATER DISTRIBUTION SYSTEM
CONVENTIONAL WATER TREATMENT
W
UPGRADED WATER TREATMENT
UPGRADED TREATMENT & REVERSE OSMOSIS

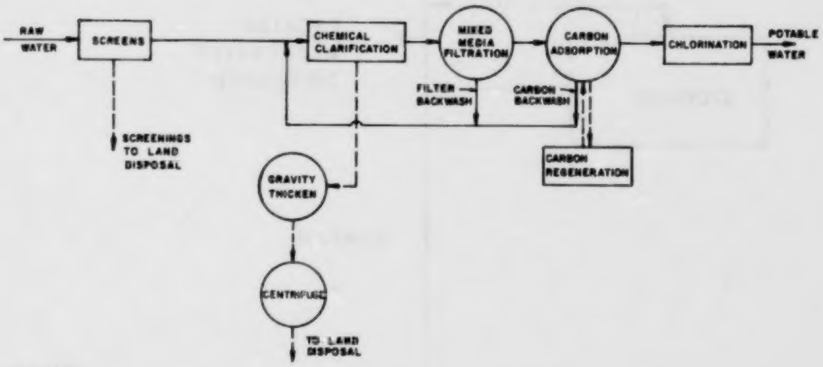
NOTE: SEE FIGURE 7 FOR FLOW DIAGRAM OF EACH TREATMENT SYSTEM.

Figure 6. SYSTEM SCHEMATIC WASTEWATER DISCHARGE - WATER INTAKE

CONVENTIONAL WATER TREATMENT


RAW WATER
SCREENS
CHEMICAL CLARIFICATION
SAND FILTRATION
CHLORINATION
POTABLE WATER
SCREENINGS TO LAND DISPOSAL
CHEMICAL SLUDGE
FILTER BACKWASH WATER
GRAVITY THICKEN
CENTRIFUGE
TO LAND DISPOSAL

UPGRADED WATER TREATMENT


RAW WATER
SCREENS
CHEMICAL CLARIFICATION
MIXED MEDIA FILTRATION
CARBON ADSORPTION
CHLORINATION
POTABLE WATER
SCREENINGS TO LAND DISPOSAL
FILTER BACKWASH
CARBON BACKWASH
CARBON REGENERATION
GRAVITY THICKEN
CENTRIFUGE
TO LAND DISPOSAL

WASTEWATER TREATMENT

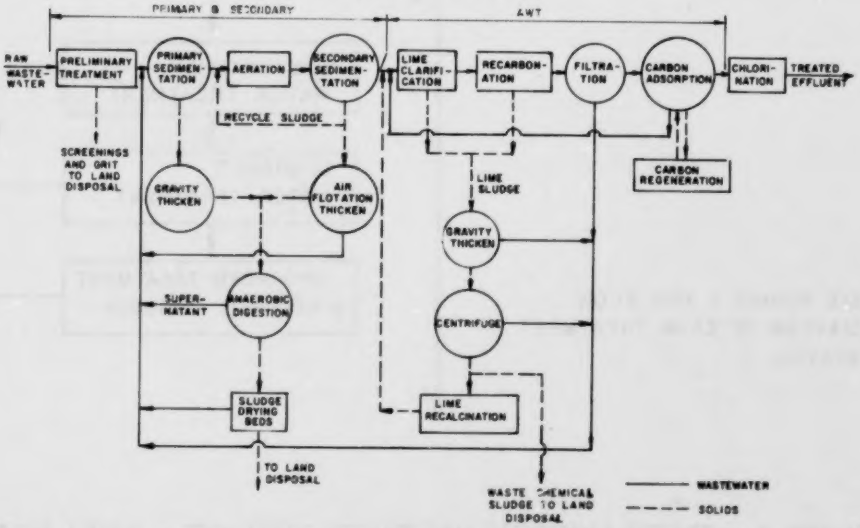

PRIMARY & SECONDARY
AWT
RAW WASTE-WATER
PRELIMINARY TREATMENT
PRIMARY SEDIMEN-TATION
AERATION
SECONDARY SEDIMEN-TATION
LIME CLARIFI-CATION
RECARBON-ATION
FILTRA-TION
CARBON ADSORPTION
CHLORI-NATION
TREATED EFFLUENT
RECYCLE SLUDGE
SCREENINGS AND GRIT TO LAND DISPOSAL
GRAVITY THICKEN
AIR FLOTATION THICKEN
LIME SLUDGE
CARBON REGENERATION
GRAVITY THICKEN
SUPER-NATANT
ANAEROBIC DIGESTION
CENTRIFUGE
SLUDGE DRYING BEDS
LIME RECALCINATION
TO LAND DISPOSAL
WASTE CHEMICAL SLUDGE TO LAND DISPOSAL
WASTEWATER
SOLIDS

Figure 7. WATER AND WASTEWATER TREATMENT SYSTEMS

Conventional Water Treatment (CT) - Alum clarification, rapid sand filtration, chlorination, gravity thickening, centrifugation and land disposal of alum sludge.

Upgraded Water Treatment (UT) - Alum clarification, mixed-media filtration, granular carbon adsorption with on-site carbon regeneration, chlorination, gravity thickening of alum sludge, centrifugation and land disposal.

The capabilities of these alternative systems are discussed in Sections 5 and 6. The typical concentrations of organics in treated effluent shown in Table 24 imply the following percentage removals:

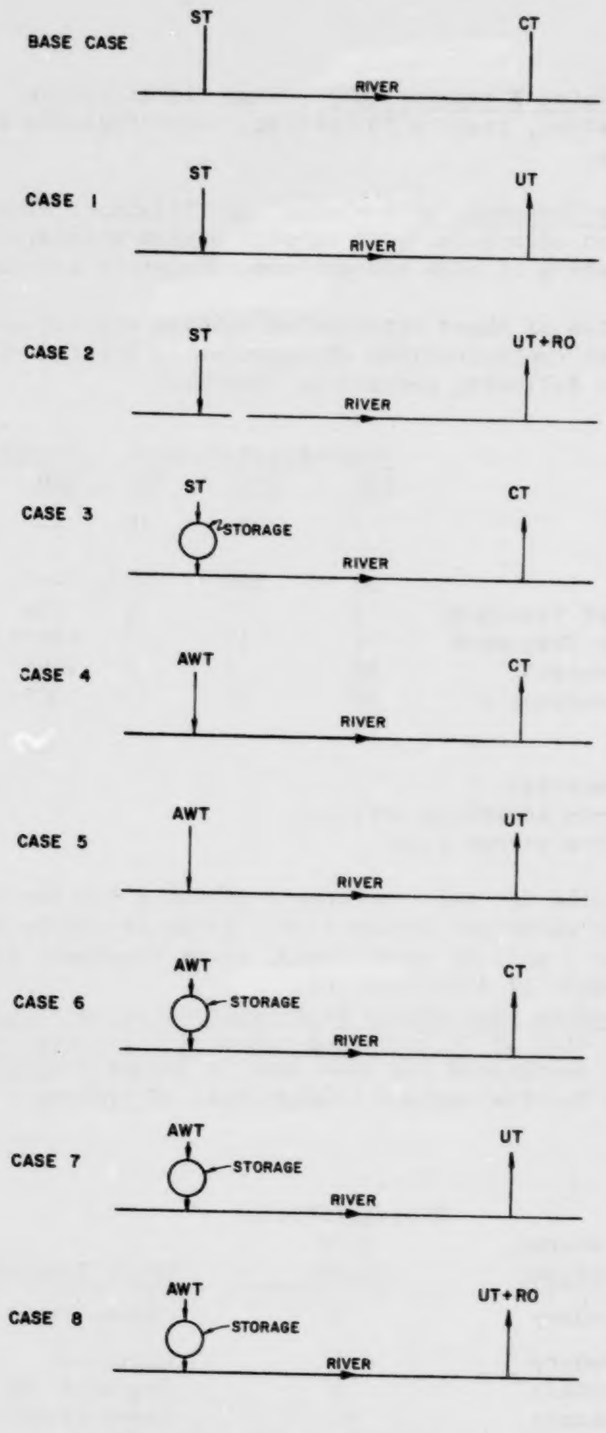
	Concentration, mg/l			Percentage Removal		
	BOD	COD	TOC	BOD	COD	TOC
Stream Flow	5	30	10	--	--	--
Effluents						
Secondary	30	100	40	--	--	--
Advanced Wastewater Treatment	2	20	8	93*	80	80
Conventional Water Treatment	<1	10	5	>80**	67	50
Upgraded Water Treatment	ND	2	1	100**	93	90
Upgraded Water Treatment & Reverse Osmosis	ND	<1	<1	100**	>97	>90

ND = None Detected
*Removal from secondary effluent
**Removal from stream flow

The above results for water treatment assume a quality at the intake within 20 percent of that shown for stream flow. It would not be possible to achieve a BOD of less than 1 mg/l by conventional water treatment if the stream water contained high levels of dissolved BOD.

The minimum system that should be considered is secondary wastewater treatment, stream flow of 24 hours and conventional water treatment. This minimum system is designated the Base Case in Figure 8 along with eight other cases. The cases involve various combinations of treatment and storage as follows:

Case	Wastewater Treatment	Storage/Stream Flow (days)	Water Treatment
Base	Secondary	1	Conventional
1	Secondary	1	Upgraded
2	Secondary	1	Upgraded and Reverse Osmosis
3	Secondary	>1	Conventional
4	AWT	1	Conventional
5	AWT	1	Upgraded
6	AWT	>1	Conventional
7	AWT	>1	Upgraded
8	AWT	>1	Upgraded and Reverse Osmosis


BASE CASE
ST
CT
RIVER
CASE 1
ST
UT
RIVER
CASE 2
ST
UT+RO
RIVER
CASE 3
ST
STORAGE
CT
RIVER
CASE 4
AWT
CT
RIVER
CASE 5
AWT
UT
RIVER
CASE 6
AWT
STORAGE
CT
RIVER
CASE 7
AWT
STORAGE
UT
RIVER
CASE 8
AWT
STORAGE
UT+RO
RIVER

ST — SECONDARY WASTEWATER TREATMENT
AWT — ADVANCED WASTEWATER TREATMENT
CT — CONVENTIONAL WATER TREATMENT
UT — UPGRADED WATER TREATMENT
RO — REVERSE OSMOSIS
SEE FIGURE 7 FOR FLOW DIAGRAM OF EACH SYSTEM

Figure 8. TREATMENT SYSTEM ALTERNATIVES

The cases were selected because they (1) incorporate technically feasible treatment processes that could be used in full scale systems, and (2) illustrate a range of product water quality and costs.

Detailed costs for the unit treatment processes are contained in Appendix B.

COST ESTIMATES

The construction costs are based on January 1977 information and were developed from equipment cost data supplied by manufacturers, cost data from actual plant construction, unit takeoffs from actual and conceptual designs, and published data. The costs should be particularly useful for estimating the relative economics of alternative treatment systems and in the preliminary evaluation of general cost level to be expected for a proposed project.

Construction costs were developed by determining and then aggregating the cost of the following eight principal components: (1) excavation and sitework, (2) manufactured equipment, (3) concrete, (4) steel, (5) labor, (6) pipe and valves, (7) electrical and instrumentation, and (8) buildings. These eight categories were utilized to facilitate accurate cost updating. The separation of cost components will also be helpful when costs are being adjusted for site specific, geographic and other special conditions. The eight categories include the following general items:

Excavation and Sitework - Work related only to the applicable process and does not include any general sitework such as sidewalks, roads, driveways, or landscaping.

Manufactured Equipment - Estimated purchase cost of pumps, drives, process equipment, specific process controls and other items which are factory made and sold with equipment.

Concrete - Delivered cost of ready mix concrete and concrete forming materials.

Steel - Reinforcing steel for concrete and miscellaneous steel not included within the Manufactured Equipment category.

Labor - Labor associated with installing manufactured equipment, piping and valves, constructing concrete forms and placing concrete and reinforced steel.

Pipe and Valves - Cast iron pipe, steel pipe, valves, fittings and associated support devices are combined into a single category.

Electrical and Instrumentation - Process electrical equipment, wiring and general instrumentation associated with the process equipment.

Buildings - In lieu of segregating building costs into several components this category represents all material and labor costs associated with the building, including heating, ventilating, air conditioning, lighting, normal convenience outlets, and slab and foundation.

The subtotal of the costs of these eight categories includes the cost of material and equipment purchase and installation, and subcontractor's overhead and profit. To this subtotal, a 15 percent allowance has been added to cover miscellaneous items not included in the cost takeoff as well as contingency items. Experience at many treatment facilities has indicated that this 15 percent allowance is reasonable.

Construction costs are not the final capital costs, because they do not include costs for engineering, legal, fiscal, and administrative and interest during construction. These items are added to construction cost to obtain capital cost as shown in Appendix B.

Operation and maintenance data were developed for: (1) energy requirements, (2) maintenance material requirements, (3) labor requirements, and (4) total operation and maintenance cost. The requirements were determined from operating data at existing plants, at least to the extent possible. Where such information was not available, assumptions were made based upon the author's and equipment manufacturer's experience.

Energy requirements were developed for both process energy and building related energy, and are presented in terms of kwh and/or Btu per year. This approach was used to allow ready adjustment for geographical influence upon energy cost.

Maintenance material costs include the cost of periodic replacement of component parts necessary to keep the process operable and functioning. Examples of maintenance material items included are valves, motors, instrumentation, and other process items of similar nature. The maintenance material requirements do not include the cost of chemicals required for process operation.

The labor requirement includes both operation and maintenance labor, and is presented in terms of hours per year.

COMPARISON OF ALTERNATIVES

A cost comparison is included for each case with two different percentages of wastewater reuse and three different wastewater plant-water plant size combinations:

- Wastewater reuse percentages of 5 and 20 percent, that is, wastewater discharge constitutes 5 and 20 percent, respectively, of the total wastewater-stream flow mixture. These percentages were arbitrarily selected to represent a range of conditions that may encompass actual conditions in many locations.

- The plant capacities used for the comparison are:

Treatment Plant Capacity, mgd	
Wastewater	Water
50	5
5	50
25	25

These capacities were selected to illustrate a range from large wastewater discharge above a small intake to small discharge above a larger intake.

In determining water quality, it was assumed that dilution is the only effect on organics removal caused by the use of differing percentages of wastewater reuse. In addition, the estimated organic removals do not consider any beneficial effect from storage time at the wastewater treatment plant.

Capital, operation and maintenance, and total annual costs for each water and wastewater treatment system are summarized in Table 31. These costs are taken from the detailed breakdown in Appendix B. Total annual costs for finished water (in dollars per year and dollars per thousand gallons of water produced) are shown in Table 32 for the Base Case and each of the eight cases for three combinations of wastewater and water treatment plant capacities. Also shown in Table 32 is the estimated finished water quality for each case with blends of 5 and 20 percent wastewater at the water intake.

Similar costs were prepared for treatment systems with increased reliability and are summarized in Tables 33 and 34. These cost estimates are for treatment plants which are virtually 100 percent reliable. Increased reliability for treatment systems in these estimates is achieved by including standby units for most treatment processes, including grit chambers, clarifiers, aeration basins and equipment, filters, chemical feed systems, chemical clarification units, recarbonation systems and granular carbon contactors. Also included are costs for standby power at both water and wastewater treatment plants. Covered concrete storage basins with one day holding capacities are included at water treatment plants. A more detailed summary of the treatment processes for which standby units are included is given with the design criteria and cost data in Appendix B. Water quality from the increased reliability system is assumed to be the same as from conventional systems.

Increased reliability wastewater treatment system capital costs range from 16 to 37 percent higher and increased reliability water treatment system capital costs range from 11 to 59 percent higher.

	CAPITAL COST			TOTAL ANNUAL COST		
Capacity (mgd)	Standard Design ($4,000)	Reliable ($1,000)	Difference (percent)	Standard Design (7,000/yr)	Reliable ($1,000)	Difference (percent)
WWTP - Secondary						
1	2,050	2,812	37	313	394	26
10	10,934	13,064	19	1,556	1,823	17
50	35,443	40,995	16	5,528	6,218	12
WTP - Conventional						
1	1,451	2,310	59	213	288	35
10	5,895	7,344	25	774	911	18
50	18,042	19,949	11	2,605	2,815	8

Case 1 (secondary wastewater treatment and upgraded water treatment) is the lowest cost case that produces finished water with TOC concentration below 2 mg/l ($0.56/1,000 gallons for standard design systems and $0.71/1,000 gallons for increased reliability systems). A comparison between Case 1 and

TABLE 31

COST SUMMARY - WATER AND WASTEWATER TREATMENT SYSTEMS

(See Text and Figure 7 for Description of Systems and Appendix B for Cost Details)

TREATMENT SYSTEM	PLANT CAPACITY, mgd				
	1	5	10	25	50
Secondary (Activated Sludge)					
Capital, $1,000	2,050	6,239	10,934	21,443	35,443
O & M, $1,000/year	145	370	660	1,524	2,617
Total Annual Cost, $1,000/year*	313	883	1,556	3,285	5,528
AWT					
Capital, $1,000	4,782	14,005	23,309	45,948	76,302
O & M, $1,000/year	333	813	1,358	2,982	5,317
Total Annual Cost, $1,000/year*	723	1,963	3,273	6,756	11,583
Conventional Water Treatment					
Capital, $1,000	1,451	3,766	5,895	11,033	18,042
O & M, $1,000/year	93	183	290	609	1,122
Total Annual Cost, $1,000/year*	213	494	774	1,515	2,605
Upgraded Water Treatment					
Capital, $1,000	2,412	4,347	6,745	13,039	20,971
O & M, $1,000/year	131	237	369	752	1,362
Total Annual Cost, $1,000/year*	329	596	923	1,823	3,084
Upgraded Water Treatment and Reverse Osmosis					
Capital, $1,000	3,715	9,379	16,277	34,568	60,945
O & M, $1,000/year	323	1,025	1,889	4,388	8,446
Total Annual Cost, $1,000/year*	629	1,797	3,226	7,228	13,449
Earthen Wastewater Storage Reservoir					
Capital, $1,000, for:					
1 day storage	42	113	197	418	697
4 day storage	96	349	596	1,075	2,230
10 day storage	197	697	1,075	--	--
30 day storage	481	1,478	--	--	--
Earthen Wastewater Storage Reservoir (Con't)					
O & M, $1,000/year	0	0	0	0	0
Total Annual Cost, $1,000/year*					
1 day storage	4	11	19	39	66
4 day storage	9	33	56	101	210
10 day storage	19	66	101	--	--
30 day storage	45	140	--	--	--

*Construction costs amortized for 20 years at 7 percent interest.

TABLE 32

TOTAL COST AND WATER TREATMENT PRODUCT WATER QUALITY

WATER AND WASTEWATER TREATMENT SYSTEMS

Case	Total Costs $/yr ($/1,000 gal water produced) 50 mgd WWTP & 5 mgd WTP	5 mgd WWTP & 50 mgd WTP	25 mgd WWTP & 25 mgd WTP	Water Treatment Plant Product Water Quality (Concentration, mg/1) For 20% Wastewater Reuse** BOD	COD	TOC	For 5% Wastewater Reuse** BOD	COD	TOC
Base Case (ST + CT)	6,022,000 (3.30)	3,488,000 (0.191)	4,800,000 (0.526)	2	14	8	1.2	11	5.8
Case 1 (ST + UT)	6,124,000 (3.36)	3,967,000 (0.217)	5,108,000 (0.560)	ND	3.1	1.6	ND	2.3	1.2
Case 2 (ST + UT + RO)	7,325,000 (4.01)	14,332,000 (0.785)	10,513,000 (1.15)	ND	1.3	<1.6	ND	1.0	<1.2
Case 3 (ST, Storage*, + CT)	6,088,000 (3.34)	3,499,000 (0.192)	4,839,000 (0.530)	2	14	8	1.2	11	5.8
Case 4 (AWT + CT)	12,077,000 (6.62)	4,568,000 (0.250)	8,271,000 (0.906)	0.9	9.2	4.8	1.0	9.7	5.0
Case 5 (AWT + UT)	12,179,000 (6.67)	5,047,000 (0.277)	8,579,000 (0.940)	ND	2.0	1.0	ND	2.1	1.0
Case 6 (AWT, Storage*, + CT)	12,143,000 (6.65)	4,579,000 (0.251)	8,310,000 (0.911)	0.9	9.2	4.8	1.0	9.7	5.0
Case 7 (AWT, Storage*, + UT)	12,245,000 (6.71)	5,058,000 (0.277)	8,618,000 (0.944)	ND	2.0	1.0	ND	2.1	1.0
Case 8 (AWT, Storage*, + UT & RO)	13,446,000 (7.37)	15,423,000 (0.845)	14,023,000 (1.54)	ND	0.8	<1.0	ND	0.9	<1.0

Note: WWTP = Wastewater Treatment Plant, WTP = Water Treatment Plant, ND = None Detected, ST = Secondary Wastewater Treatment, AWT = Advanced Wastewater Treatment, CT = Conventional Water Treatment, UT = Upgraded Water Treatment, RO = Reverse Osmosis.

*Costs include 1 day storage at the wastewater treatment plant.

**Percent wastewater in the total stream flow.

TABLE 33

COST SUMMARY - FOR INCREASED RELIABILITY WATER AND WASTEWATER TREATMENT SYSTEMS

(See Text and Figure 7 for Description of Systems and Appendix B for Cost Details)

INCREASED RELIABILITY TREATMENT SYSTEM	PLANT CAPACITY, MGD				
	1	5	10	25	50
Secondary (Activated Sludge					
Capital, $1,000	2,812	8,232	13,064	24,841	40,995
O & M, $1,000/year	164	442	752	1,680	2,853
Total Annual Cost, $1,000/year *	394	1,118	1,823	3,719	6,218
AWT					
Capital, $1,000	6,747	18,115	28,786	54,861	90,277
O & M, $1,000/year	354	912	1,497	3,247	5,739
Total Annual Cost, $1,000/year *	906	2,398	3,860	7,751	13,150
Conventional Water Treatment					
Capital, $1,000	2,310	4,795	7,344	12,805	19,949
O & M, $1,000/year	97	191	306	646	1,176
Total Annual Cost, $1,000/year *	288	586	911	1,698	2,815
Upgraded Water Treatment					
Capital, $1,000	3,191	5,603	8,458	15,336	23,217
O & M, $1,000/year	134	251	393	804	1,436
Total Annual Cost, $1,000/year *	398	712	1,087	2,064	3,344
Upgraded Water Treatment & Reverse Osmosis					
Capital, $1,000	4,972	11,614	19,419	37,505	62,957
O & M, $1,000/year	399	1,183	2,128	4,750	8,809
Total Annual Cost, $1,000/year *	809	2,138	3,723	7,830	13,976
Concrete Water Storage Reservoir 1 day capacity					
Capital, $1,000	589	1,759	3,160	6,976	12,247
O & M, $1,000/year	0	0	0	0	0
Total Annual Cost, $1,000/year *	56	166	298	658	1,156
Concrete Water Storage Reservoir 4 day capacity					
Capital, $1,000	1,471	5,765	10,283	20,143	36,545
O & M, $1,000/year	0	0	0	0	0
Total Annual Cost, $1,000/year *	139	544	971	1,901	3,450

*Construction costs amortized over 20 years at 7 percent interest.

TABLE 34

TOTAL COST AND WATER TREATMENT PRODUCT WATER QUALITY
INCREASED RELIABILITY WATER AND WASTEWATER TREATMENT SYSTEMS

Case	Total Costs $/yr ($/1,000 gal water produced)			Water Treatment Plant Product Water Quality (Concentration, mg/l)					
	50 mgd WWTP & 5 mgd WTP	5 mgd WWTP & 50 mgd WTP	25 mgd WWTP & 25 mgd WTP	For 20% Wastewater Reuse**			For 5% Wastewater Reuse**		
				BOD	COD	TOC	BOD	COD	TOC
Base Case (ST + CT)	6,970,000 (3.82)	5,089,000 (0.279)	6,075,000 (0.666)	2	14	8	1.2	11	5.8
Case 1 (ST + UT)	7,096,000 (3.89)	5,618,000 (0.308)	6,441,000 (0.706)	ND	3.1	1.6	ND	2.3	1.2
Case 2 (ST + UT + RO)	8,522,000 (4.67)	16,250,000 (0.890)	12,207,000 (1.34)	ND	1.3	<1.6	ND	1.0	<1.2
Case 3 (ST, Storage*, + CT)	7,036,000 (3.86)	5,100,000 (0.279)	6,114,000 (0.670)	2	14	8	1.2	11	5.8
Case 4 (AWT + CT)	13,902,000 (7.62)	6,369,000 (0.349)	10,107,000 (1.11)	0.9	9.2	4.8	1.0	9.7	5.0
Case 5 (AWT + UT)	14,028,000 (7.69)	6,898,000 (0.378)	10,473,000 (1.15)	ND	2.0	1.0	ND	2.1	1.0
Case 6 (AWT, Storage*, + CT)	13,968,000 (7.65)	6,380,000 (0.350)	10,146,000 (1.11)	0.9	9.2	4.8	1.0	9.7	5.0
Case 7 (AWT, Storage*, + UT)	14,094,000 (7.72)	6,909,000 (0.379)	10,512,000 (1.15)	ND	2.0	1.0	ND	2.1	1.0
Case 8 (AWT, Storage*, + UT & RO)	15,520,000 (8.50)	17,541,000 (0.961)	16,278,000 (1.78)	ND	0.8	<1.0	ND	0.9	<1.0

Note: WWTP = Wastewater Treatment Plant, WTP = Water Treatment Plant, ND = None Detected, ST = Secondary Wastewater Treatment, AWT = Advanced Wastewater Treatment, CT = Conventional Water Treatment, UT = Upgraded Water Treatment, RO = Reverse Osmosis. Costs for all cases include 1 day storage at the water treatment plant.

*Costs include 1 day storage at the wastewater treatment plant.

**Percent wastewater in the total stream flow.

Case 4 (AWT and conventional water treatment) indicates that the total cost for Case 4 ranges from 15 to 97 percent higher, depending upon the size combination, while the organic quality of the finished water, in terms of BOD, COD and TOC concentrations, is much better for Case 1 than Case 4. Thus, it is more expensive and less efficient, with regard to finished water quality, to provide AWT for the wastewater discharge upstream than to provide upgraded treatment at the water treatment plant.

Since some water treatment must be provided, whether or not there is any upstream wastewater discharge, it may be desirable in some instances to provide the most intensive treatment at the water treatment plant rather than at the wastewater treatment plant. Effects of the wastewater discharge on the stream ecosystem, eutrophication potential, and aesthetic considerations are probably more pertinant to whether secondary or advanced wastewater treatment should be provided than is the effect on quality of the downstream water supply.

SECTION 8

CASE STUDIES

The purpose of this section is to discuss three cases that involve the indirect reuse of wastewater through location of wastewater treatment plant discharges into streams above water supply intakes.

1. Occoquan, Virginia. This project, scheduled to begin operation in April 1978, is to discharge highly treated wastewater to a storage reservoir on Bull Run that serves as a water supply source for about 500,000 people in the Washington, D.C. area.
2. Huron River, Michigan. The project discussed in this case was not implemented. It involves the proposed discharge of 41 mgd of nitrified and filtered secondary effluent about 12 miles above a 4 mgd water supply intake.
3. Passaic Basin, New Jersey. The Passaic River is an existing situation that involves a long history of indirect wastewater reuse.

The intent is to present an objective, non-judgemental discussion of the facts prepared from a review of available information on each case. On-site investigations or extensive interviews with individuals involved were not conducted.

The case studies illustrate considerations involving the planned discharge of wastewater to water supply sources in three different areas in the United States. These cases also highlight the thought processes which have progressed over the past several years. For example, at Occoquan the main concern appeared to be reliability and viruses while in the Passaic Basin biological contaminants/viruses were the primary concern initially and now trihalomethanes and organics are receiving more attention.

OCCOQUAN, VIRGINIA

The Occoquan watershed drains some 600 square miles southwest of Washington, D.C., and is the source of drinking water for about 500,000 people in the Washington, D.C. area. The general location of the watershed is shown in Figure 9. The first storage of runoff from the watershed for water supply occured in 1950 when the Alexandria Water Company built a small dam near the town of Occoquan. The current 1,700 acre, 9.8 billion gallon reservoir was created in 1958 by the construction of the Upper or High dam. Concurrent with construction of the dam were rapidly increasing pressures for development in the watershed. From 1940 to 1960, the population in the Washington, D.C. area nearly doubled. Most of the growth since the late 1950's has occurred in Northern Virginia and suburban Maryland.

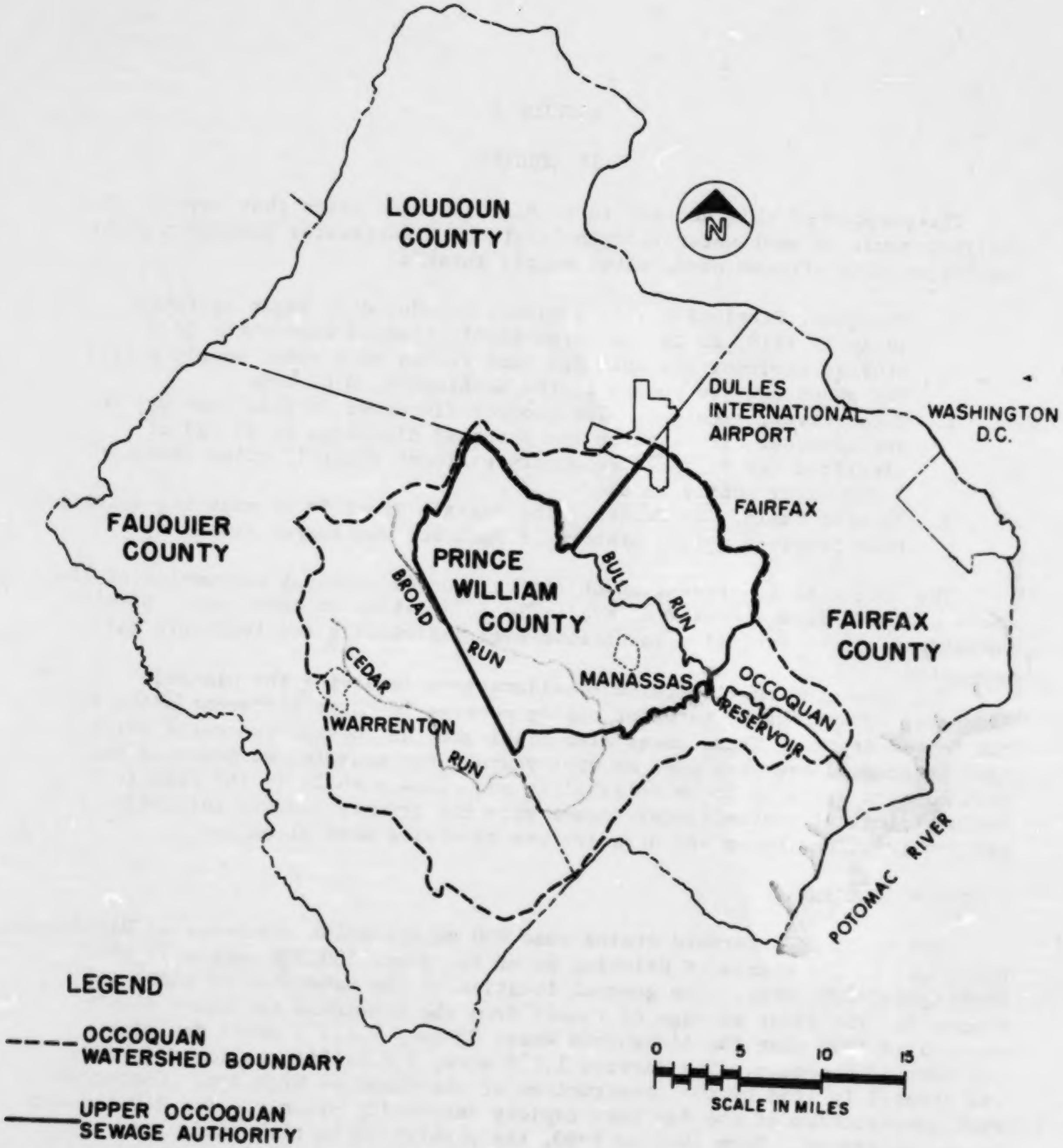

LOUDOUN
COUNTY
N
DULLES
INTERNATIONAL
AIRPORT
WASHINGTON
D.C.
FAUQUIER
COUNTY
FAIRFAX
PRINCE
WILLIAM
COUNTY
BROAD
RUN
BULL
RUN
FAIRFAX
COUNTY
CEDAR
MANASSAS
OCCOQUAN
RESERVOIR
WARRENTON
RUN
POTOMAC
RIVER
LEGEND
OCCOQUAN
WATERSHED BOUNDARY
UPPER OCCOQUAN
SEWAGE AUTHORITY
0
5
10
15
SCALE IN MILES

Figure 9. LOCATION OF OCCOQUAN WATERSHED

The development in the watershed caused increasing concern by the Virginia State Health Department and State Water Control Board (SWCB) over the potential effects of wastewater discharges and urban runoff on the reservoir water quality. In December, 1959, requirements of 90 percent BOD removal and 15 days detention in holding ponds were established for standard treatment plants in the watershed. In early 1960, the State Health Department added effluent limits of 20 mg/1 BOD and suspended solids and algae removal for discharges to the reservoir. Although the concerns of the Health Department continued to increase, by 1970 there were 25 wastewater treatment plants in the Occoquan basin with a certified capacity of 5.95 mgd. Population was projected to increase 10-fold to 800,000 by the year 2000.

The SWCB commissioned studies of the Occoquan Reservoir quality and the basin pollution problems by Metcalf and Eddy in 1969. The Reservoir was found to be highly eutrophic in summer and early fall, with heavy growths of blue-green algae and anaerobic below a depth of 10 feet. It was concluded that sewage effluents were a major cause of the highly eutrophic conditions; that natural runoff from the watershed contains, at times, enough inorganic phosphorus to contribute the entire allowable load to the reservoir; and that treatment plant effluents should not be discharged to the reservoir during the algal growth season. The solution proposed was construction of secondary plants, with export of the secondary effluents to a tributary to the Potomac River. The cost of such an export system was found to be less than abandoning the Reservoir and providing comparable water supply facilities elsewhere.

Public hearings were held on the export proposal in the fall of 1970 with several citizen groups expressing opposition based upon concerns about the cost of the proposed treatment and export system, the potential impacts on growth in previously underdeveloped areas, and the need for a solution which would not merely transport the problem to the Potomac River. A special bond election was held on September 22, 1970 with the result that the funds for the export system were defeated by a 2:1 margin. At the same election, $153,000,000 of bonds for other facilities (libraries, parks, schools, etc.) were approved. The portion of the sewer bonds associated with the export system ($9,000,000) were deleted from the total sewer bonds proposed (39,000,000) which included $30,000,000 for upgrading existing plants in the basin and subjected to a vote in the November, 1970 election. The revised $30,000,000 bond proposal (without export) passed by a 4:1 margin.

A significant development in mid-1970 was the appointment of Noman Cole as Chairman of the SWCB. Cole, a nuclear engineer, perceived the Occoquan situation as a major environmental issue. Taking actions somewhat unique in the pollution control field, Cole personnally made an independent analysis of alternative approaches to handling the wastewaters in the Occoquan basin, including a trip to California to evaluate advanced wastewater treatment at the South Lake Tahoe Public Utility District. Cole drafted a report which compared AWT and discharge to the Occoquan Reservoir with the export alternative and reviewed his report in December, 1970, with the four jurisdictions involved (Fairfax County, Prince William County, Manassas Park, and Manassas).

The report, which was finalized in January, 1971, first reviewed conventional wastewater treatment, the performance of the Tahoe AWT plant, existing discharges to the Occoquan Reservoir, and the export alternative. A chart similar to Figure 10 was presented which compared the quantities of BOD,

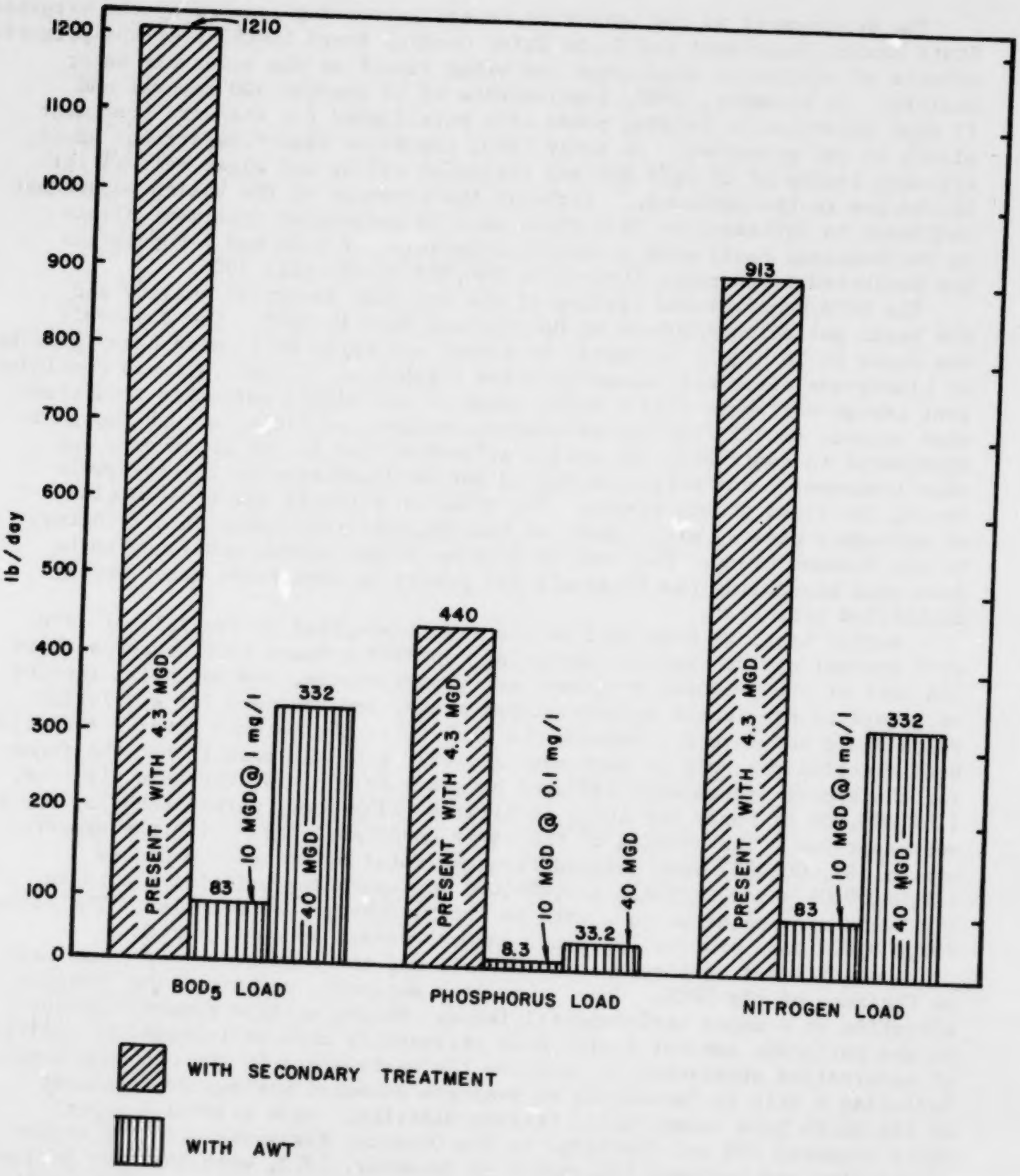


Figure 10. DISCHARGES TO OCCOQUAN RESERVOIR WITH SECONDARY TREATMENT AND AWT

phosphorus, and nitrogen being discharged to the reservoir at the-then-existing flow of 4.3 mgd of secondary effluent to those quantities which would be discharged at flows of 10 mgd and 40 mgd of AWT effluent. The 40 mgd flow would represent 12 percent of the annual inflow to the reservoir and 46 percent of the July low flow to the reservoir. This analysis concluded that even if flows should eventually reach 10 times the existing wastewater flows, the quantities of pollutants discharged to the reservoir would be substantially reduced by AWT.

A cost analyses indicated that the capital cost savings for the four jurisdictions would be at least $20,000,000 if the AWT alternative were adopted. The actual savings were expected to be even greater because AWT standards had been adopted for discharges to the Potomac while the original cost estimate for export were based on export of secondary effluent. Although the costs of the export system were a prime factor motivating the evaluation of the AWT alternative, the SWCB report also concluded:

> *Hopefully, this will help kill the archaic and technically out-of-date philosophy that the "solution to the control of water pollution is export and dilution"--or more simply and clearly stated, "Do not dump it in my yard - but it is all right to dump it in my neighbors."*
>
> *We would have a valuable asset (e.g., a 10 to 40 mgd clean water source between now and 1985). This clean water source will help stretch our water supply as well as protect our valuable park land investments on the Occoquan.*
>
> *In summary, we will have preserved the Occoquan Reservoir water quality as well as provide a major source of its water supply. Further, in this approach, we will have spent our efforts, energy, talent, and financial resources for treatment of water, rather than for expensive export pipes which do not clean up any water but just move the problem elsewhere!*
>
> *This approach of thoroughly cleaning up waste is equivalent to developing a new water supply resource.*

The report also presented an outline of administrative considerations that would be a part of the in-basin reuse concept. These considerations later were the nucleus of a formal State of Virginia policy for the Occoquan Watershed (which is discussed later). As reflected in newspaper articles, the initial response of the jurisdictions involved was positive:

> *It is kind of refreshing to see the State Water Control Board take a positive position of leadership in the field of pollution.... Chairman Prince William, County Board of Supervisors, Potomac News, 12/2/70.*
>
> *We feel that this concept is a breakthrough - Warrenton Town Manager Edward Brower. The Fauquier Democrat, 12/10/70.*

The whole thing was a breath of fresh air - Jason Paige, Chairman, the Fauquier Water and Sanitation Authority. The Fauquier Democrat, 12/10/70.

If you're wondering where that gale-force sigh of relief came from, it's just us, pleased to have something to be positive about regarding the Occoquan Reservoir.

And positive we are about the report State Water Control Board Chairman Noman M. Cole, Jr. released Wednesday in which he concludes it would be both better and cheaper to treat sewage in the Occoquan Watershed ala-Lake Tahoe than to export the effluent from the basin. Editorial, Northern Virginia Sun, 12/4/70.

A preliminary State policy for the Occoquan Watershed based on the in-basin reuse concept was issued in late January, 1971 and a public hearing was scheduled for March 31, 1971. Concurrently, the four jurisdictions involved formed the Upper Occoquan Sewage Authority (UOSA) to implement a regional wastewater system.

At the public hearing on the reuse concept, the Virginia State Health Department and the downstream water supply utility (the Fairfax County Water Authority - FCWA) attacked the proposed plan on the basis that viruses discharged in the AWT effluent present a health threat. Both agencies urged that the wastewaters be exported from the basin. The SWCB conducted a further evaluation of the virus question in April, 1971 and issued a report on this issue. This evaluation concluded that:

(1) The 25 existing discharges of marginally treated secondary effluent were discharging significant quantities of virus to the Occoquan Reservoir.

(2) The existing discharges constituted 2 percent of the annual water supply and 10 percent in low flow months.

(3) There were no apparent virus health problems related to the water supply.

(4) The lack of virus problems was due to a combination of the facts that there were 20 to 25 miles of travel between the points of wastewater discharge and water intakes and 100 to 190 days travel time between these points, and that the FCWA downstream water treatment processes provided the conditions needed to assure kill of any surviving virus - turbidity of 0.1-1 JTU and effective chlorination.

(5) There were cases in the world where water supplies contained a higher percentage of wastewater than would be the case for Occoquan and yet no water supply related virus health problems were apparent.

(6) The discharge of AWT effluent should substantially reduce the existing level of discharges of virus to the Occoquan Reservoir.

(7) The virus issue was not one of substance based on available evidence.

After further review of the issue, the FCWA concluded "...*that the upgrading and replacement of the present treatment plants with an advanced waste treatment facility will not result in any increase in risk and will most probably reduce the current level of pollutants.*"

The U.S. EPA wrote in response to the controversy:

> *...AWT processes utilized provide a substantial improvement in virus removal over conventional secondary processes and additionally allow more effective chlorination of the final effluent. There is no doubt that the provision of a Tahoe-type AWT treatment facility in the Upper Occoquan Watershed, even with a discharge twice that of the present secondary plants, will provide for an improvement of water quality, including public health aspects. In the reservoir.*

The Virginia Department of Health stated:

> *While this Department still has reservations about the proposed policy the above cited circumstances or evidence indicates the risk is a minimal or accepted one provided all the safety features are included in the design and a meaningful management and surveillance program is included. Therefore, this Department will cease its opposition to the policy and will work with the Water Control Board in establishing the requirements for management and surveillance program.*

With the virus issue resolved, the SWCB adopted a formal policy for the Occoquan watershed on July 26, 1971.

The SWCB policy called for AWT of all wastewaters in the basin with discharge of a high quality effluent to the Occoquan Reservoir. The SWCB stated that this approach offered several advantages over that of export, including (1) solution of the sewage-related Occoquan water quality problems, while preventing further degradation of the Potomac estuary; (2) elimination of a very costly export system; (3) preservation of the water supply resources of the watershed and (4) minimized the possibility of a major siltation problem from the construction of the export line. The policy also established a total yearly wastewater flow allocation for the watershed through 1985-1990, as well as suggesting allotments to each jurisdiction. It also called for establishment of a monitoring program to provide data on plant operation and the effect of discharge on the quality of the Reservoir and monitoring of siltation problems.

Until the regional AWT plant was available, the SWCB policy required the removal of "maximum amounts" of BOD, COD, suspended solids, and phosphorus at existing plants. "Modest" expansion of existing plants was permitted provided they were abandoned when the regional facility became available, and if no increased loading to the stream resulted.

The policy presented detailed requirements for the AWT facility and collection system. No more than three, and preferably only two, plants were specified for the watershed area. All plants were required to be at least 15 miles (preferably 20 miles) above the Fairfax County Water Authority's water intake.

The major treatment processes specified by the policy to meet these standards were:

1. Primary settling.
2. Activated sludge.
3. Lime coagulation and settling for phosphorus removal.
4. Two stage recarbonation with intermediate settling.
5. Mixed media filtration.
6. Nitrogen removal (Selective ion exchange was later selected by the designer as the process to be used for nitrogen removal.)
7. Granular carbon adsorption.
8. Chlorination.
9. Storage, on site.

The policy specified the following effluent quality as measured on a weekly average basis: BOD = 1.0 mg/l, COD = 10.0 mg/l, suspended solids = 0 mg/l, nitrogen = 1 mg/l, phosphorus = 0.1 mg/l as P, methylene blue active substances (MBAS) = 0.1 mg/l, turbidity = 0.4 TU, and coliform bacteria of less than 2 per 100 ml.

The initial wastewater flow allocation was established as 10 mgd, with 5 mgd incremental increases in flow being licensed only if the monitoring program showed that the AWT effluent was not creating a water quality or public health hazard in Reservoir. A maximum watershed allotment of 39.3 mgd was specified for 1985-1990.

The policy required that the initial plant must have 100 percent backup capacity, but after the success of the concept was established, the ratio of on-line treatment to standby capacity could be as high as 4:1. The plant was to be designed so that the failure of a single component would not interrupt plant operations necessary to meet the final effluent requirements. In a similar vein, the policy also specified two independent sources of outside power and one on-site power supply to minimize the risk of treatment interruption due to power failure. Changes from the plant design requirements were permitted only with written approval from the SWCB, which reserved the right to hold public hearings on any proposed design changes. The plant must be staffed 24 hours per day, 7 days per week, with a minimum of five people per shift.

In addition to the design requirements for the plant, the policy also presented specific requirements concerning the design of pumping stations. These dealt with minimum standards for standby pumps, on-site power supply, dual off-site power sources designed so that failure of a single component would not degrade pumping capacity, flow measuring and recording, and provision of retention basins of a minimum one-day capacity.

The recently formed UOSA had begun the process of selecting a design consultant and retained the firm of CH2M/Hill in August, 1971 to prepare a facility plan. The four member jurisdiction of UOSA then began the process of drawing up a service agreement which would define the allocations of capacity and distribution of costs for the regional system. Although the facility plan was completed on schedule in January, 1972, the completion of the service agreement was delayed for several months due to disagreements among the jurisdictions concerning allocation of capacity and funding of the Authority. Any concerns over the indirect reuse concepts inherent in the project were completely overshadowed by these disagreements over capacity and funding. The reuse issue simply did not surface again as an obstacle to process implementation after the virus question was settled in May, 1971.

The Authority was on the edge of politic destruction by one or more of the member jurisdictions throughout early 1972. A key factor in the eventual implementation of the project was the provision in the Occoquan policy that the existing plants in the watershed could be expanded only modestly in the interim period until the regional plant was available. As all of the jurisdictions were facing pressures for development, the threat of restraint of available sewage capacity proved to be a major incentive in the ultimate adoption of a service agreement on June 21, 1972 - just 9 days before the grant funds for the project would have been lost.

In August, 1972 the Regional Council of Governments (COG) reviewed the facility plan for the Occoquan project. The review addressed only two points related to reuse - (1) nutrient control and (2) virus removal. The COG review of the nutrient question concluded that the AWT process proposed would "go a long way toward abating the pollution problem in the Occoquan Reservoir". In regard to virus, the COD review concluded that the travel distance of 20 miles, travel time of 100-190 days, and effective water treatment downstream were an adequate combination to provide control of viruses. COG approved the project with the reuse aspect receiving relatively minor consideration among factors such as effects on jurisdictions' ability to control growth, conformance to regional plans, air pollution, etc.

In accordance with the schedule approved by the State and EPA, the plans and specifications for the total project with an initial rated capacity of 10.9 mgd were submitted in May, 1973. Subsequent to submission of the plans, the State and EPA advised UOSA that funding limitations would not permit award of one contract for the total project. The project had to be split for funding in 2 fiscal years and EPA required that each split must result in an operable unit. Instead of splitting the project into logical construction phases, such as earth work, concrete, buildings, etc., UOSA had to award contracts for total operable unit processes in the treatment plant. For example, the first plant contract was for construction of the filtration units and carbon adsorption system. This change, delays in plan review and approvals, delays from protests over bid awards, delays in EPA approvals due to new grant regulations which required all UOSA jurisdictions to comply with infiltration/inflow, user change, and industrial cost regulations, and the unprecedented rate of inflation in 1974 caused the total project costs, including a regional collection system, to increase from the originally estimated $43,600,000 to about $76,000,000.

Each jurisdiction may select its own method of recovering its share of the local capital costs. However, the O & M costs must be allocated to each customer in proportion to his usage. The UOSA operation and maintenance costs at 10.9 mgd are projected to be 65¢ per 1,000 gallons. Assuming an average usage per connection of 8,000 gallons per month, the UOSA operation and maintenance costs per connection would be $5.20 per month.

HURON RIVER, MICHIGAN

The Huron River serves as a water supply for the City of Flat Rock, Michigan. The Flat Rock water treatment plant was designed for an ultimate capacity of 4 mgd, but at present only about 25 percent of the design capacity is being utilized.

In February, 1976 a proposal was considered to construct a 41 mgd wastewater treatment facility that would discharge the the Huron River at French Landing, about 14 miles upstream from the Flat Rock water treatment plant. Figure 11 is a general location map of the area. The new wastewater treatment plant would serve the City of Ypsilanti and portions of Wayne County and permit abandonment of existing treatment plants serving Ypsilanti and Ypsilanti Township. The proposed plant included secondary treatment plus nitrification, rapid sand filtration and chlorination. Daily discharge limits, developed jointly by the Water Resources Commission and the State Department of Public Health were a maximum of 10 mg/l BOD and 2 mg/l ammonia.

The following excerpts are from an environmental assessment and indicate some of the concerns associated with the proposed wastewater treatment plant at French Landing:

> *Nitrates* - *In 1995 the proposed French Landing plant will discharge about 5,800 pounds per day of NO_3-N under average daily flow conditions. At a 7 day dry weather flow of 102 cfs over Belleville Dam, this nitrate load (5,800 pounds per day) from the French Landing plant will result in a nitrate concentration in the Huron River of approximately 10.25 mg/l. This level of nitrate nitrogen in the Huron River is quite close to the EPA drinking water standard of 10 mg/l. Hence, the EPA drinking water standard for NO_3-N may be exceeded at the river water intake for the City of Flat Rock should this alternative be implemented. This potential problem could possibly be solved by restricting the concentration of nitrate nitrogen in the French Landing wastewater effluent, regulating the flow over Belleville Dame, applying denitrification treatment at the French Landing plant or removing the City of Flat Rock's water supply from the Huron River. Before this alternative could possibly be implemented the nitrate nitrogen problem in the Huron River at Flat Rock must be addressed.*
>
> *Phosphorus* - *...it is estimated that the total phosphorus concentration of the Huron River below Flat Rock will be about 0.8 mg/l under 10 year 7 day dry weather flow conditions in 1995. As a point for comparing the significance of this projected level of phosphorus it should be pointed out that at the present time the maximum reported total phosphorus concentration in the Huron River at its mouth has been 0.7 mg/l. Therefore, under this alternative slightly higher (10-15%) concentrations of total phosphorus may be expected in the Huron River at drought flow than has been experienced to date.*
>
> *Chloramines* - *In 1995 the French Landing treatment facility will be discharging an effluent containing approximately 1.0 mg/l of residual chlorine. All of this residual chlorine will be in the form of monochloramine due to the ammonia nitrogen concentrations in the effluent. Therefore, the concentration of monochloramines in the Huron River*

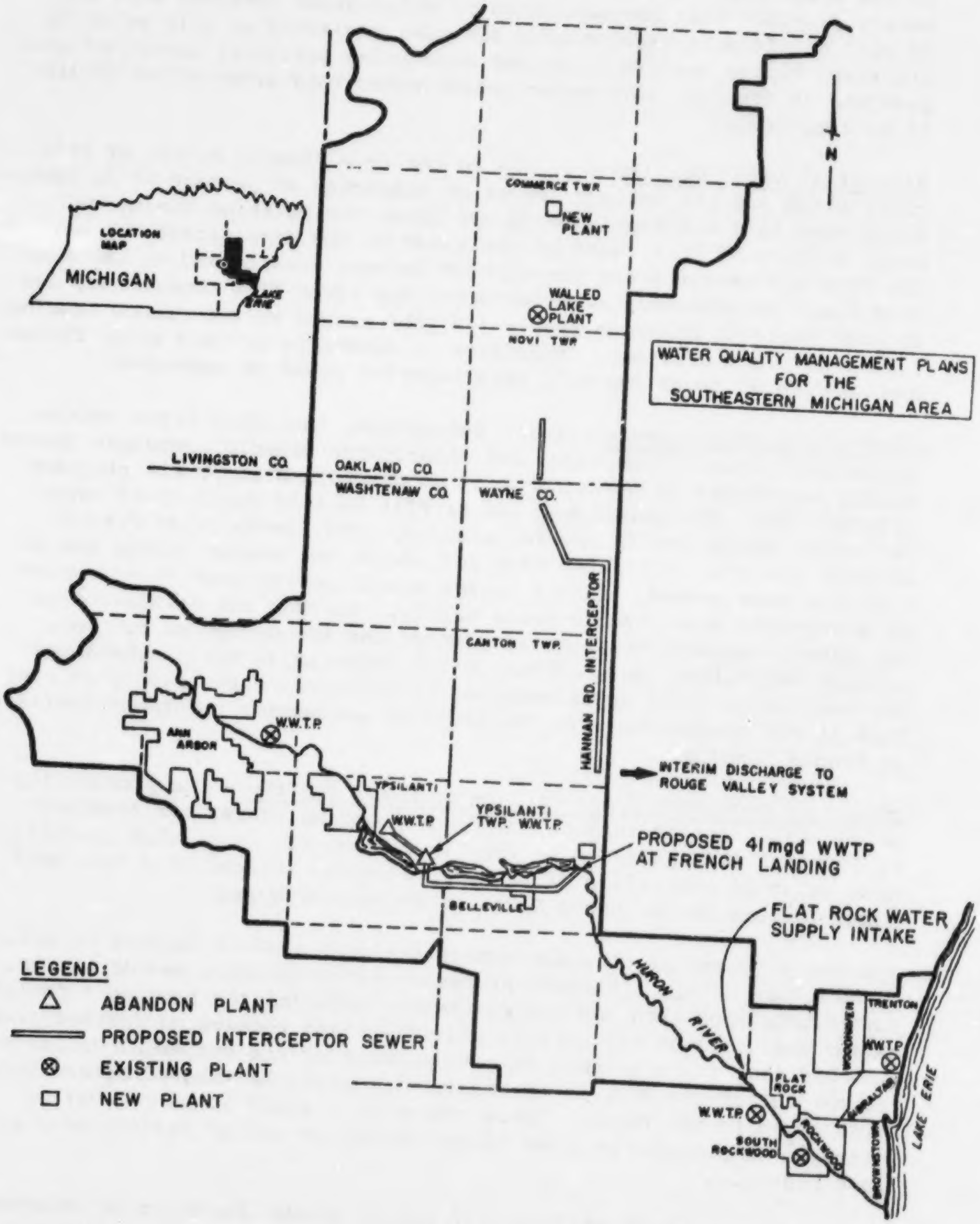

WATER QUALITY MANAGEMENT PLANS
FOR THE
SOUTHEASTERN MICHIGAN AREA
LOCATION MAP
MICHIGAN
LAKE ERIE
N
COMMERCE TWP.
NEW PLANT
WALLED LAKE PLANT
NOVI TWP.
LIVINGSTON CO.
OAKLAND CO.
WASHTENAW CO.
WAYNE CO.
CANTON TWP.
HANNAN RD. INTERCEPTOR
INTERIM DISCHARGE TO
ROUGE VALLEY SYSTEM
ANN ARBOR
W.W.T.P.
YPSILANTI
W.W.T.P.
YPSILANTI TWP. W.W.T.P.
PROPOSED 41mgd WWTP
AT FRENCH LANDING
BELLEVILLE
HURON RIVER
FLAT ROCK WATER
SUPPLY INTAKE
WOODHAVEN
TRENTON
WWTP
FLAT ROCK
W.W.T.P.
SOUTH ROCKWOOD
ROCKWOOD
GIBRALTAR
BROWNSTOWN
LAKE ERIE
LEGEND:
△ ABANDON PLANT
═ PROPOSED INTERCEPTOR SEWER
⊗ EXISTING PLANT
□ NEW PLANT

Figure 11. LOCATION MAP, HURON RIVER, MICHIGAN

below the French Landing plant will be about 0.4 mg/l at 10 year 7 day dry weather flow....the estimated residual chlorine concentration in the Huron River at the Flat Rock water supply intake will be approximately 30 ppb. This concentration of chloramines combined with the 12 mg/l of ultimate carbonaceous BOD also projected at this point in the river raises serious questions concerning potential taste and odor problems at the Flat Rock water intake under this alternative should it be implemented.

Biological Water Quality - ...due to the free flowing nature of this river reach and the optimum levels of nutrients at present it is speculated that this alternative will not alter the existing biological water quality of this reach of the river to any significant degree. The fish and invertebrate communities between French Landing and Flat Rock would be adversely affected under low river flow conditions, due to high residual chlorine levels (30 ppb) caused by the French Landing treatment plant effluent. Reduction in diversity of warm water fishes and absence of trout and cold water species could be expected.

Other Waste Constituents - Toxic substances, including trace metals, refractory organic compounds, and chlorinated organic compounds formed during wastewater chlorination will be discharged under all proposed alternatives. The downstream use at Flat Rock of Huron River water for water supply merits special mention. The discharge at French Landing (63 cfs) is diluted with 102 cfs in the stream during the 10 year low flow period. Such a system nearly constitutes direct reuse of wastewater as a potable water supply. Neither the wastewater or the water treatment systems are planned for the degree of control, process relibility, and monitoring for potentially toxic substances for such reuse. The downstream use of water for water supply at Flat Rock is not compatible with the proposed wastewater treatment facility at French Landing.

Impact of Treatment Plant Failure on Water Quality - The probability of a total plant failure of the French Landing wastewater treatment facility is considered to be very low. However, since this possibility does exist an evaluation of the environmental impacts of a treatment plant failure on the Huron River is deemed advisable.

For the purposes of this assessment analysis a plant failure is defined as the loss of all treatment processes except primary sedimentation. Under this condition the raw wastewater entering the treatment facility would pass through the primary clarifiers and receive no further treatment. In this case it is assumed that 40 percent of the suspended solids and 35 percent of the BOD_5 in the wastewater would be removed before being discharged to the river. There essentially would be no removal of nitrogen or phosphorus under these conditions and no disinfection would take place....

...A treatment plant failure will result in the discharge of increased amounts of carbonaceous and nitrogeneous oxygen demanding materials to

> *the Huron River....A mathematical simulation of a plant failure of this magnitude shows that the dissolved oxygen level in the river below French Landing will approach zero. In addition the* BOD_{20} *at Flat Rock would be about 25 mg/l if the failure occurred at drought flow. This condition would pose serious taste and odor problems in the Flat Rock water supply...*
>
> *...A failure in the disinfection process at the French Landing wastewater treatment facility will result in the discharge of massive amounts of bacteria to the river system....If the French Landing treatment facility failed under 1995 drought flow conditions, the expected bacterial concentrations in the river immediately below the plant's outfall would be on the order of* $1.1 \times 10^7/100$ *ml and* $1.4 \times 10^6/100$ *ml for total and fecal coliform bacteria, respectively. It is obvious that these bacterial levels would violate stream standards and would pose a definite health hazard in the river immediately downstream from the treatment plants....*
>
> *...Under these conditions contamination of the Flat Rock water supply source would be inevitable. Therefore, should this alternative be implemented an alternate emergency source of water and/or increase in system water storage for the Flat Rock community should be developed.*

The position of the Michigan Department of Public Health is illustrated in the following memorandum dated March 5, 1976 from William A. Kelley, Chief of the Water Supply Section:

> *I attended the February 26, 1976 meeting of the Water Resources Commission to discuss the recent proposals for the installation of a large waste treatment plant on the Lower Huron River with the outfall located below Belleville Lake at French Landing. I informed the Commission and staff during the discussion that the Flat Rock water plant would be adversely affected by such a waste discharge....*
>
> *....I indicated to the Commission that we did not feel water reuse was an acceptable alternative in Michigan and this is exactly what we would be facing in this particular situation. It was indicated that the department would have concerns relative to the possibility of virus, chemicals originating from industrial spills, etc. as well as the possibility of research indicating the need of a maximum contaminant level for organohalides in the future....I also raised the point of potential overflows from the wastewater plant or simple operator error.... (A staff member of the Commission) made a comment about being able to design around any difficulties that would be involved but I disputed this idea by saying that practical operation of even a theoretically perfect plant would still not be desirable at this particular point. The Water Resources Commission seemed to appreciate our position and concerns.*
>
> *I concluded the statement that I made relative to this particular problem by indicating that if the decision is made to proceed with*

a large wastewater discharge at French Landing, the city of Flat Rock would not be able to utilize their water treatment plant with the water supply source from the Huron River. I pointed out that there seemed to be several alternatives to solving the problem with three that would come to mind immediately being:

1. *Abandon the Flat Rock water plant and make the necessary connections to the Detroit water supply system to serve the city of Flat Rock.*
2. *Continue to use the Flat Rock water plant but provide a new source by pumping raw water from an approved location in Lake Erie up to the Flat Rock plant, and*
3. *Continue to use the Flat Rock water plant but pipe the treated wastewater effluent to a point below the Flat Rock water supply intake.*

An important component in the position of the Health Department was the conclusion that funding for the alternate water supply for Flat Rock, including retirement of outstanding bonds for the water plant, should be included in the financing of the proposed wastewater treatment project.

The proposed alternative of the French Landing plant was only one of many alternatives which were considered for the area. The proposal was abandoned, in part due to the impact of wastewater discharges on the quality of the Flat Rock water supply. Other factors, including political considerations associated with connecting another city's water supply system were considered unfavorable to this alternative. As of January, 1978, it appears that the alternative of one large plant at French Landing will be replaced by three separate plants: two much further upstream and one downstream from the Flat Rock water supply intake.

PASSAIC BASIN, NEW JERSEY

The Passaic River, although one of the most polluted rivers in the East, still serves satisfactorily as the major water supply source for northeastern New Jersey. Serving as a backbone for industrial development since the 1790's, the Passaic River has long been a source for water power, recreation, potable water supply, and a means for disposing of municipal and industrial wastes.

Beginning in the 1850's and continuing through 1890 the river served without any treatment as a direct source of potable water. By 1890 the river downstream from the City of Paterson was considered too polluted to use, due to wastes discharged from the industrial centers. In 1902, the first rapid sand filtration plant was built at Little Falls, New Jersey, where it is still in use today. Over the years there have been many controversies over water rights for uses such as power, flow maintenance in canals, and private and public water supplies.

The Passaic Valley Water Commission serves over 600,000 people and is the chief water supply agency for 15 northern New Jersey communities including Paterson, Passaic and Clifton. Presently there are about 115 municipal and industrial wastewater treatment plants locating within the 485 square mile area of watershed above the Little Falls water intake (see

Figure 12). The total wastewater flow discharged in the watershed is about 55 mgd, which represents up to 60 percent of the total flow in the river at Little Falls during drought years. In the past the wastewater treatment plants have achieved between 75 and 95 percent removals of BOD, with an average of about 85 percent removal. The BOD in the river at Little Falls has averaged from 2 to 5 mg/l, but is as high as 10 mg/l during periods of low flow.

The treatment processes used at the 100 mgd Little Falls plant include: two-stage screening, addition of powdered activated carbon for taste and odor control, free residual, or breakpoint chlorination with rapid mixing, alum coagulation, flocculation, sedimentation, dechlorination, filtration, pH adjustment with caustic soda and post-chlorination. In the past when activated carbon costs were much lower than today, powdered activated carbon was applied regularly. Presently it is used only during emergencies when the water quality at the intake is poor due to high organics in waste spills upstream.

In 1971 John Wilford, then Chief of the Bureau of Water Supply in the State of New Jersey, Department of Environmental Protection, wrote:

> *....Notwithstanding the poor quality of the water in the river, the Passaic Valley Water Commission has been consistently able to produce water from this source which meets the requirements of the New Jersey Potable Water Standards....No studies have been conducted to determine the incidence of viruses in either the river water or the treated water, primarily because of the impracticability of conducting vital determinations on a routine basis. It is reasonable to assume, however, that the water treatment process must effectively remove any viruses which may be present; otherwise there would have been epidemics of infectious hepatitis, etc. among the consumers....*

That the situation constitutes indirect reuse of the wastewaters for potable water supply is widely understood and accepted as indicated in the following statement made in 1973 by Wendell R. Inhoffer, the General Superintendent and Chief Engineer of the Passaic Valley Water Commission:

> *The Commission, with its rights to 75 mgd at Little Falls admittedly depends upon this wastewater discharge to meet its requirements.*

When the demand for potable water was increasing during World War II, the quality of the water in the Passaic River had deteriorated such that there were many complaints received about the drinking water treated by the 1902 filtration plant. As reported by Wendell Inhoffer:

> *During this period, it was not unusual for the Commission to receive 800 complaints a day of phenolic and chemical taste and odors, primarily due to the increase in industrial pollution created by wartime industry.*

Soon after this, in 1948, the Commission added free residual, or breakpoint chlorination, to control taste and odor causing materials, particularly free ammonia. According to Wendell Inhoffer:

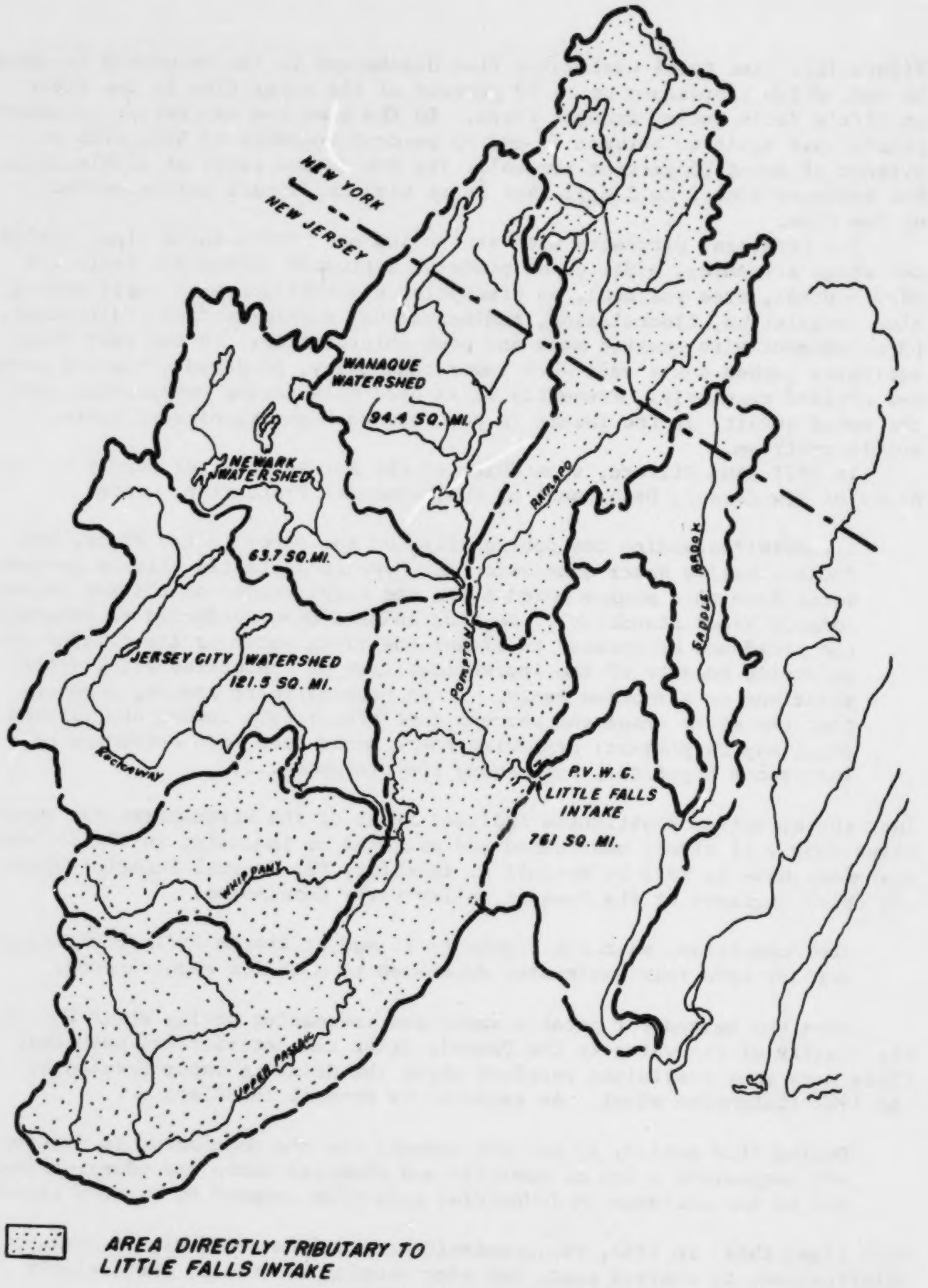

NEW YORK
NEW JERSEY
WANAQUE WATERSHED
94.4 SQ. MI.
NEWARK WATERSHED
63.7 SQ. MI.
JERSEY CITY WATERSHED
121.5 SQ. MI.
ROCKAWAY
WHIPPANY
UPPER PASSAIC
RAMAPO
POMPTON
SADDLE BROOK
P.V.W.C. LITTLE FALLS INTAKE
761 SQ. MI.
AREA DIRECTLY TRIBUTARY TO LITTLE FALLS INTAKE

Figure 12. WATERSHEDS OF THE PASSAIC RIVER AND TRIBUTARIES

> *It can be stated that without the use of breakpoint chlorination, the Passaic River could not be safely used as a source of potable water supply. However, the use of breakpoint chlorination is costly....It ....(is)....apparent that the influence of sewage treatment plant discharges resulting in free ammonia in the raw river water significantly affects the cost of treatment....Commission experience indicates that as long as one maintains a free chlorine residual of at least 50 percent after prechlorination, taste and odor standards will be maintained.*

Currently, the average chlorine dose, which depends mostly upon the ammonia concentration in the raw water, ranges from 15 to 25 mg/l. The ammonia concentration, typically varies from 0.5 to 5 mg/l, with an average of 1 to 2 mg/l.

In the mid-1960's, while commercial and industrial development was continuing to occur in the watershed, and with the realization that the ultimate wastewater flow could approach 100 mgd, the Commission became concerned about possible contaminants not normally identified in their regular testing program. In 1968 the Commission undertook a pilot study of possible means of treatment to remove soluble organics, after concluding that their program which included powdered activated carbon treatment was not adequate. In the study, a filter containing granular activated carbon was found to remove substantial portions of dissolved organics.

After several more years of studies it was concluded that granular activated carbon filters were not as effective as granular carbon adsorption following filtration. At present, no regular program of activated carbon treatment is provided at the plant. However, there does appear to be a good chance in the future for the addition of a tertiary carbon adsorption step and research toward this is continuing.

The similarity in regard to water reuse between the Passaic Valley Water Commission water treatment plant and an advanced wastewater treatment plant was noted by Wendell Inhoffer in 1973 when he wrote:

> *The 100 mgd treatment plant....has sometimes been characterized as the tertiary sewage treatment plant for the Passaic Basin....*

When also in 1973 Wendell Inhoffer wrote that:

> *Proposed regional sewage treatment facilities are being redesigned to include tertiary treatment for plants located above the Commission's Little Falls intake....It is anticipated that with the implementation of tertiary sewage treatment plants above the intake, the presence of ammonia will be reduced.*

it seemed that the construction of AWT plants upstream would soon become quite common; however, this may still be several years away, since in early 1978 no AWT plants have been built and it appears only one is likely to be built within the next four or five years.

No major move toward the construction of large regional wastewater treatment plants has occurred either. This may in part be due to the position of the Water Commission, who recently opposed a proposed expansion from

16 to 50 mgd of a secondary wastewater treatment facility at Troy Hills. The opposition was primarily due to the negative effect such a large wastewater discharge would have on the water quality downstream.

Presently one of the main concerns of the Water Commission is the presence of trihalomethanes, and particularly for the potential for higher concentrations at the users tap because of the chance for long retention times in the distribution system. Virus removal is not considered to be a problem, primarily because of the large chlorine dosages and long reaction times provided.

REFERENCES

1. National Academy of Sciences, "Drinking Water and Health", Part 1, U.S. Department of Commerce, NTIS PB-270 422; Part II NTIS PB-270 423, 1977.

2. Namminga, H. and Wilhm, J., "Heavy Metals in Water, Sediments and Chironomids", Journal WPCF, pp. 1725-1731, July 1977.

3. Toth, S.J., "Metallic Elements in Inland Waterways", Journal AWWA, pp. 455-459, April 1968.

4. Kroner, R.C., "The Occurrence of Trace Metals in Surface Waters", in "Traces of Heavy Metals in Water Removal Processes and Monitoring", EPA - 902/9-74-001, pp. 311-322, November 1973.

5. Teurikian, K. K., et al., "The Variations of Si, Cl, Na, Ca, Sr, Ba, Co, Ag, in the Neuse River, North Carolina", Limnol. Ocean., 12: 702, 1967.

6. Shapiro, M. A., et al., "Intensive Study of the Water at Critical Points on the Monogahela, Allegheny, and Ohio Rivers in the Pittsburgh, Pennsylvania Area", University of Pittsburgh, 1967.

7. Symons, J.M., et al., "National Organics Reconnaissance Survey for Halogenated Organics", Journal AWWA, pp. 634-647, November 1975.

8. "Preliminary Assessment of Suspected Carcinogens in Drinking Water", Interim Report to Congress, EPA, Washington, D.C., June 1975.

9. Malcolm, R.J., and Durum, W.H., "Organic Carbon and Nitrogen Concentrations and Annual Organic Carbon Load of Six Selected Rivers of the United States", Geological Survey Water Supply Paper 1817-F. (undated)

10. Anderson, C., and Maier, W.J., "The Removal of Organic Matter from Water Supplies by Ion Exchange", Water Resources Research Center, Bulletin 91, University of Minnesota, February 1977.

11. Zemansky, G.M., "Removal of Trace Metals in Conventional Water and Wastewater Treatment", M.S. Thesis, University of Colorado, Boulder, Colorado, 1973.

12. Lindstedt, K.D., et al., "Quality Considerations in Successive Water Use", Journal WPCF, p. 1681, 1971.

13. "Report on Hyperion Pilot Plant No. 1 - Appendix A to the Los Angeles Water Recycling Project Report", City of Los Angeles Dept. of Water and Power, September 1972.

14. Chen, K.Y., et al., "Trace Metals in Wastewater Effluents", Journal WPCF, pp. 2665-2675, December 1974.

15. Argo, D.G., "Orange County's Water Factory 21", presented at the Wastewater Treatment and Reuse Seminar, South Lake Tahoe, Stateline, Nevada, October 27-29, 1976.

16. Hodam, R.H., "The Best Way to Remove Heavy Metals Might Turn Out To Be...Activated Sludge!", Bulletin CWPCA, pp. 54-55, April 1976.

17. Davis, J.A., III, And Jacknow, J., "Heavy Metals in Wastewater in Three Urban Areas", Journal WPCF, p. 2293, September 1975.

18. Klein, L. A., et al., "Sources of Metals in New York City Wastewater", Journal WPCF, p. 2754, December 1974.

19. Chandler, R. L., et al., "Pollution Monitoring With Total Organic Carbon Analysis", Journal WPCF, pp. 2791-2803, December 1976.

20. Bunch, R. L., et al., "Organic Materials in Secondary Effluents", Journal WPCF, pp. 122-126, 1961.

21. Rebhun, M., and Manka, J., "Classification of Organics in Secondary Effluents", Environmental Science and Technology, p. 606, 1971.

22. Manka, J., et al., "Characterization of Organics in Secondary Effluents", Environmental Science and Technology, p. 1017, November 1974.

23. Sachdev, D. R., et al., "Apparent Molecular Weights of Organics in Secondary Effluents", Journal WPCF, p. 570, 1976.

24. Katz, S., et al., "The Determination of Stable Organic Compounds in Waste Effluents at Microgram Per Liter Levels by Automatic High-Resolution Ion Exchange Chromatography", Water Research, Vol. 6, pp. 1029-1037, 1972.

25. Helfgott, T., et al., "Analytic and Process Classification of Effluents", Proc. ASCE, SA 3, pp. 779-803, June 1970.

26. Jolley, R. L., "Chlorination Effects on Organic Constituents in Effluents from Domestic Sanitary Sewage Treatment Plants", Oak Ridge National Lab., Publication No. 565, ORNL-TM-4290, October 1973.

27. Glaze, W. H., and Henderson, J. E., "Formation of Organochlorine Compounds From the Chlorination of Municipal Secondary Effluent", Journal WPCF, p. 2511, 1975.

28. "Interim Report on Montgomery Simulation - Study of Formation and Removal of Volatile Chlorinated Organics", Unpublished EPA Report, July 8, 1975.

29. Manahan, S. E., "Environmental Chemistry", Willard Grant Press, Boston, Mass., 1972.

30. Stumm, W. and Morgan, J. J., "Aquatic Chemistry", Wiley - Interscience, New York, 1970.

31. "Trace Metal and Metal-Organic Interactions in Natural Waters", P.C. Singer, editor, Ann Arbor Science, Ann Arbor, Michigan, 1973.

32. "Aqueous Environmental Chemistry of Metals", A. J. Rubin, editor, Ann Arbon Science, Ann Arbor, Michigan, 1974.

33. Turekein, K. K., and Scott, M. R., "Concentrations of Cr, Ag, Mo, Ni, Co, and Mn and Suspended Material in Streams", Environmental Science and Technology, pp. 940-942, November 1967.

34. Lotse, E. G., et al., "Lindane Adsorption by Lake Sediments", Environmental Science and Technology, pp. 353-357, May 1968.

35. Streeter, H. W., and Phelps, E. B., "A Study of the Pollution and Natural Purification of the Ohio River. III. Factors Concerned in the Phenomena of Oxidation and Reaeration", Public Health Bulletin No. 146, U.S. Public Health Service, Washington, D.C., 1925.

36. O'Connor, D. J., and Dobbins, W. E., "The Mechanism of Reaeration in Natural Streams", Journal San. Engr. Div., Proc. Amer. Soc. Civil Engr., 82, p. 1115, 1956.

37. Dobbins, W. E., "BOD and Oxygen Relationships in Streams", Jour. San. Eng. Div., Proc. Amer. Soc. Civil Engr., 90, SA 3, p. 53, 1964.

38. Churchill, M. A., et al., "Prediction of Stream Reaeration Rates", Jour. San. Engr. Div., Proc. Amer. Soc. Civil Engr., 88, p. 1, 1962.

39. Langbein, E. B., and Durum, W. J., "The Aeration Capacity of Streams", USDA, Geological Survey, Bulletin, p. 542, 1967.

40. Krenkel, P. A., and Orlob, G. T., "Turbulent Diffusion and the Reaeration Coefficient", Jour. San. Engr. Div., Proc. Amer. Civil Engr., 88, p. 53, 1962.

41. Thackston, E. L., and Krenkel, P. A., "Reaeration Prediction in Natural Streams", Jour. San. Engr. Div., Amer. Soc. Civil Engr., 95 p. 65, 1969.

42. Tsivoglou, E. C., and Neal., L. A., "Tracer Measurement of Reaeration: III. Predicting the Reaeration Capacity of Inland Streams", Jour. Water Poll. Control Fed., Vol. 48, No. 12, 1976.

43. Hoover, T. C., and Arnoldi, R. A., "Computer Model of Connecticut River Pollution", Jour. Water Poll. Control Fed., p. 1970.

44. Gundelach, J. M., and Castillo, J. E., "Natural Stream Purification Under Anaerobic Conditions", Jour. WPCF, p. 1976.

45. Haith, D. A., and Chapman, D. C., "Best Practicable Waste Treatment Screening Model", Jour. of the Environmental Engr. Div., June 1977.

46. Bath, T. D., et al., "Concentration Profiles Downstream from Instantaneous Pollution Loadings", Jour. WPCF, p. 1970.

47. Grimsrud, G. P., et al., "Evaluation of Water Quality Models, A Management Guide for Planners", U.S. Dept. of Commerce, NTIS, PB-256 412 July, 1976.

48. "Manual of Treatment Techniques for Meeting the Interim Primary Drinking Water Regulations", EPA 600/8-77-005, May 1977.

49. Committee Report, "Viruses in Water", Journal AWWA, p. 491, Oct., 1969.

50. Berg, G., "Removal of Viruses from Water and Wastewater", Dept. of Civil Engineering, University of Illinois, 1971.

51. Robeck, G. G., et al., "Effectiveness of Water Treatment Processes in Virus Removal", Journal American Water Works Association, 54, p. 1275, 1962.

52. Wolf, H. W., et al., "Virus Inactivation During Tertiary Treatment", Journal AWWA, p. 526, 1974.

53. Berg, G., et al., "Removal of Poliovirus 1 from Secondary Effluent by Lime Flocculation and Sand Filtration", Journal AWWA, p. 193, Feb., 1968.

54. Hudson, H. E., Jr., "High Quality Water Production and Viral Disease" Journal American Water Works Association, 54, p. 1265, 1962.

55. Walton, G., "Effectiveness of Water Treatment Processes as Measured by Coliform Reduction", U.S. Public Health Service Publication No. 898, 1962.

56. Sproul, O. J., "Virus Inactivation by Water Treatment", Journal AWWA, p. 31, January, 1972.

57. Thorup, R. T., et al., "Virus Removal by Coagulation with Polyelectrolytes", Journal AWWA, p. 97, February, 1970.

58. Chaudhuri, M., and Englebrecht, R. S., "Removal of Viruses from Water by Chemical Coagulation and Flocculation", Journal AWWA, p. 563, Sept. 1970.

59. Manwaring, J. F., et al., "Removal of Viruses by Coagulation and Flocculation", Journal AWWA, p. 298, May, 1971.

60. Hann, V. A., "Disinfection of Drinking Water With Ozone", Journal AWWA, p. 1316, October, 1956.

61. Pavoni, J. L., et al., "Virus Removal From Wastewater Using Ozone", Water and Sewage Works, p. 59, December, 1972.

62. Majumdar, S. B., et al., "Communication-Inactivation of Poliovirus in Water by Ozonation".

63. Symons, J.M., et al., "Interim Treatment Guide for the Control of Chloroform and Other Trihalomethanes", EPA Water Supply Research Division, Cincinnati, Ohio, June 1976.

64. Eckenfelder, W.W., Jr., "Boost Plant Efficiency", Water and Wastes Engineering, pp. E1-E6, September 1972.

65. Eckenfelder, W.W., Jr., "Water Quality Engineering for Practicing Engineers", Barnes and Noble, Inc., New York, N.Y., 1970.

66. Jones, R.H., "TOC: How Valid Is It?", Water and Wastes Engineering pp. 32-33, April 1972.

67. Stenger, V.A., and Van Hall, C.E., "Analysis of Municipal and Chemical Wastewaters by an Instrumental Method for COD Determination", Journal WPCF, pp. 1755-1763, October 1968.

68. Chandler, R.L., et al., "Pollution Monitoring with Total Organic Carbon Analysis", Journal WPCF, pp. 2791-2803, December 1976.

69. Weber, W.J., Jr., and Morris, J.C., "Equilibria and Capacities for Adsorption on Carbon", Sanitary Engineering Division Journal ASCE, SA3 p. 79, June 1974.

70. Weber, W. J., Jr., "Physicochemical Processes for Water Quality Control", Wiley-Interscience, 1972.

71. Weber, W. J., Jr., and Morris, J. C., "Kinetics of Adsorption on Carbon from Solution", Sanitary Engineering Division Journal, ASCE, SA2, p. 31, April, 1963.

72. Hassler, J. W., "Activated Carbon", Chemical Publishing Co., New York 1974.

73. Joyce, R. S., and Sukenik, V. A., "Feasibility of Granular Activated Carbon Adsorption for Wastewater Renovation", U.S. Public Health Service, Report AWTR-15, October 1965.

74. Weber, W. J., Jr., "Fluid-Carbon Columns for Sorption of Persistent Organic Pollutants", Third International Conference on Water Pollution Research, Munich, Germany, 1966.

75. Morris, J. C., and Weber, W. J., Jr., "Adsorption of Biochemically Resistant Materials from Solution", U.S. Public Health Service, AWTR-9, May 1964.

76. Hager, D. G., and Rizzo, J., "Removal of Toxic Organics from Wastewater by Adsorption with Granular Activated Carbon", presented at EPA Technology Transfer Session on Treatment of Toxic Chemicals, Atlanta, Georgia, 1974.

77. Stoltenberg, D. H., "How to Reclaim a Poisoned Lake", Public Works, p. 59, March, 1972.

78. Hyndshaw, A. Y., "Activated Carbon to Remove Organic Contaminants from Water", Journal AWWA, p. 309, May 1972.

79. Hager, D. C., and Fulker, R. D., "Adsorption and Filtration with Granular Activated Carbon", Journal of the Society for Water Treatment and Examination, 17, p. 41, 1968.

80. Dostal, K. A., et al., "Carbon Bed Design Criteria Study at Nitro, W. Va.", Journal AWWA, p. 663, May 1965.

81. Flentje, M. E., and Hager, D. C., "Advance in Taste and Odor Removal With Granular Carbon Filters", Water and Sewage Works, February, 1964.

82. Hager, D. C., and Flentje, M. E., "Removal of Organic Contaminants by Granular Carbon Filtration", Journal AWWA, p. 1440, November 1965.

83. Hansen, R. E., "Granular Carbon Filters for Taste and Odor Removal", Journal AWWA, p. 176, March 1972.

84. Cameron, C. D., et al., "Organic Contaminants in Raw and Finished Water", Journal AWWA, p. 419, September 1974.

85. McCreary, J. L. and Snoeyink, V. L., "Granular Activated Carbon in Water Treatment", Journal AWWA, pp. 437-444, August 1977.

86. Bishop, D. F., et al., "Studies on Activated Carbon Treatment", Journal WPCF, p. 188, February 1967.

87. Parkhurst, J. D., et al., "Pomona Activated Carbon Pilot Plant", Journal WPCF, p. R70, October 1967.

88. Middleton, F. M., "Organic Residue Removal", Symposium on Nutrient Removal and Advanced Waste Treatment", Tampa, Florida, November 1968.

89. Smith, C. E., and Chapman, R. L., "Recovery of Coagulant, Nitrogen Removal, and Carbon Regeneration in Wastewater Reclamation", FWPCA Grant Report, Grant WPD-85, June 1967.

90. McCarty, P. L., et al., "Organics Removal by Advanced Waste Treatment", presented at the 1977 AWWA Conference, May 1977.

91. DeWalle, F.B., and Chain, E. S., "Removal of Organic Matter by Activated Carbon Columns", EED Journal, ASCE, p. 1089, October 1974.

92. Edwards, V.H., and Schubert, P.F., "Removal of 2, 4-D and Other Persistent Organic Molecules From Water Supplies by Reverse Osmosis", Journal AWWA, pp. 610-616, October 1974.

93. Merten U., et al., "Organic Removal by Reverse Osmosis", American Chemical Society Symposium on Organic Residue Removal from Wastewaters, Atlantic City, New Jersey, September 1968.

94. Zemansky, G.M., "Removal of Trace Metals During Conventional Water Treatment", Journal AWWA, pp. 606-609, October 1974.

95. Nilsson, R., "Removal of Metals by Chemical Treatment of Municipal Wastewater", Water Research, 5, p. 51, 1971.

96. Patterson, J.W., "Wastewater Treatment Technology", Ann Arbor Science, 1975.

97. Smith, S.B., "Trace Metals Removal by Activated Carbon", in "Traces of Heavy Metals in Water Removal Processes and Monitoring", EPA 902/9-74-001, pp. 55-70, November 1973.

98. Sigworth, E.A., and Smith, S.B., "Adsorption of Inorganic Compounds by Activated Carbon", Journal AWWA, pp. 386-391, July 1972.

99. Thiem, L., et al., "Removal of Mercury From Drinking Water Using Activated Carbon", Journal AWWA, pp. 447-451, August 1976.

100. Linstedt, K. D., et al., "Trace Element Removals in Advanced Wastewater Treatment Processes", Journal WPCF, Vol. 43, No. 7, pp. 1507-1513, July 1971.

101. Cohen, J. M., "Trace Metal Removal by Wastewater Treatment", EPA Technology Transfer, January 1977.

102. Ferguson, J. F., and Anderson, M. Q., "Chemical Forms of Arsenic in Water Supplies and Their Removal", pp. 137-158, in "Chemistry of Water Supply Treatment and Distribution" by A. J. Rubin, Ann Arbor Science, 1974.

103. Shen, Y. S., "Study of Arsenic Removal From Drinking Water", Journal AWWA, pp. 543-598, August 1973.

104. Maruyama, T., et al., "Metal Removal by Physical and Chemical Treatment Processes", Journal WPCF, pp. 962-975, May 1975.

105. Hem, J.D., "Study and Interpretation of the Chemical Characteristics of Natural Water", Geological Survey Water - Supply Paper 1473, 1959.

106. Sittig, M., "Toxic Metals, Pollution Control and Worker Protection", Noyes Data Corporation, 1976.

107. Logsdon, G.S., and Symons, J.M., "Removal of Heavy Metals by Conventional Treatment", in "Traces of Heavy Metals in Water Removal Processes and Monitoring", EPA-902/9-74-001, pp. 225-256, November 1973.

108. Culp, G.L., and Culp, R.L., "New Concepts in Water Purification", Van Nostrand Reinhold Environmental Engineering Series, 1974.

109. Parker, C.L., and Fong, C.C., "Fluoride Removal: Technology and Cost Estimates", Industrial Wastes, pp. 23-27, 1975.

110. Harmon, J.A., and Kalichman, S.B., "Defluoridation of Drinking Water in Southern California", Journal AWWA, pp. 245-254, 1965.

111. Hem, J.D., and Durum, W.H., "Solubility and Occurrence of Lead in Surface Water", Journal AWWA, pp. 562-568, August 1973.

112. Humenick, M.J., and Schnoor, J.L., "Improving Mercury (II) Removal by Activated Carbon", Journal AWWA, pp. 1249-1262, December 1974.

113. Logsdon, G.S., and Symons, J.M., "Mercury Removal by Conventional Water Treatment Techniques", Journal AWWA, pp. 554-562, August 1973.

114. "Process Design Manual for Nitrogen Control", EPA, October 1975.

115. Culp, R.L., et al., "Advanced Wastewater Treatment", 2nd Edition, Van Nostrand Reinhold, 1978.

116. Furukawa, D.H., "Removal of Heavy Metals From Water Using Reverse Osmosis", in "Traces of Heavy Metals in Water Removal Processes and Monitoring", EPA 902/9-74-001, pp. 179-188, November 1973.

117. "Water Quality and Treatment", American Water Works Association, 3rd Edition, 1971.

118. Sawyer, C.N., and McCarty, P.L., "Chemistry for Sanitary Engineers", 2nd Edition, McGraw-Hill, 1967.

119. United States Public Health Service, "Manual of Recommended Water-Sanitation Practice:, 1946.

120. Walton, G., "Relation of Treatment Methods to Limits for Coliform Organisms in Raw Waters", Journal AWWA, pp. 1281-1289, October 1956.

121. Clarke, N.A., et al., "AWWA Committee Report on Viruses in Water", Journal AWWA, pp. 491-494, October 1969.

122. Ford, D.L., "Factors Affecting Variability from Wastewater Treatment Plants", Progress in Water Technology, v. 8, no. 1, pp. 91-111, Permagon Press 1976.

123. Gilbert, W.G., "Relation of Operation and Maintenance to Treatment Plant Efficiency", Journal WPCF, pp. 1822-1833, July 1976.

124. Ettlich, W.F., "A Comparison of Oxidation Ditch Plants to Competing Processes for Secondary and Advanced Treatment of Municipal Wastes", Contract No. 68-03-2186, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1977.

125. Grovhong, T.R., "Plant Size Influence on Performance in Activated Sludge Systems with Application to Regional Wastewater Treatment Planning", University of California, Davis, OWRT-B-173-CAL(1), 1973.

126. Hovey, W.H., et al., "Optimal Size of Regional Wastewater Treatment Plants", University of California, Davis, OWRT Project-B-173-CAL, August 1976.

127. Dean, R.B. and Forsythe, S.L., "Estimating the Reliability of Advanced Waste Treatment", Water and Sewage Works, pp. 87-89, June 1976 and pp. 57-60, July 1976.

128. "Federal Guidelines: Design, Operation, and Maintenance of Wastewater Treatment Facilities", U.S. Department of the Interior, Federal Water Quality Administration, September 1970.

129. Jopling, W.F., et al., "Fitness Needs for Wastewater Reclamation Plants", Journal AWWA, pp. 626-629, March 1971.

130. "Development of Reliability Criteria for Water Reclamation Operations", California State Department of Health, Water Sanitation Section, August 1973.

131. "Wastewater Reclamation Criteria", An excerpt from the California Administrative Code, Title 22, Division 4, Environmental Health, 1975.

132. Culp, G.L., "Fail-Safe Plant Slated for Virginia", Water and Wastes Engineering, p. 51, November 1972.

133. Craun, G.F., et al., "Water Borne Disease Outbreaks in the U.S., 1971-74", Journal AWWA, pp. 420-424, August, 1976.

134. Ames, B.N., et al., "Methods for Detecting Carcinogens and Mutagens with the Salmonella/Mammalian-Microsome Mutagenicity Test", Mutation Research pp. 347-364, 1975.

135. Bryan, F.L., "Disease Transmitted by Foods Contaminated with Wastewater", In EPA Document No. 660/2-74-041, pp. 16-45, June 1974.

136. World Health Organization, "Assessment of the Carcinogenicity and Mutagenicity of Chemicals", W.H.O. Technical Report Series 566, pp. 19, 1974.

137. Stokinger, H.E., "Toxicology and Drinking Water Gontaminants", Journal AWWA, pp. 399-402, July, 1972

138. Mantel, N. and Bryan, W.R., "Safety Testing of Carcinogenic Agents", Journal National Cancer Institute, pp. 455-470, 1961.

139. Tardiff, R.G., "Health Effects of Organics: Risk and Hazard Assessment of Ingested Chloroform", Journal AWWA, pp. 658-661, December 1977.

APPENDIX A

WASTEWATER RECLAMATION SYSTEM RELIABILITY CRITERIA
STATE OF CALIFORNIA

WASTEWATER
RECLAMATION CRITERIA

An Excerpt from the

CALIFORNIA ADMINISTRATIVE CODE
TITLE 22, DIVISION 4

ENVIRONMENTAL HEALTH

1975

STATE OF CALIFORNIA
DEPARTMENT OF HEALTH
Water Sanitation Section
2151 Berkeley Way, Berkeley 94704

INTENT OF REGULATIONS

The intent of these regulations is to establish acceptable levels of constituents of reclaimed water and to prescribe means for assurance of reliability in the production of reclaimed water in order to ensure that the use of reclaimed water for the specified purposes does not impose undue risks to health. The levels of constituents in combination with the means for assurance of reliability constitute reclamation criteria as defined in Section 13520 of the California Water Code.

As affirmed in Sections 13510 to 13512 of the California Water Code, water reclamation is in the best public interest and the policy of the State is to encourage reclamation. The reclamation criteria are intended to promote development of facilities which will assist in meeting water requirements of the State while assuring positive health protection. Appropriate surveillance and control of treatment facilities, distribution systems, and use areas must be provided in order to avoid health hazards. Precautions must be taken to avoid direct public contact with reclaimed waters which do not meet the standards specified in Article 5 for nonrestricted recreational impoundments.

Article 6. Sampling and Analysis

60321. **Sampling and Analysis.** (a) Samples for settleable solids and coliform bacteria, where required, shall be collected at least daily and at a time when wastewater characteristics are most demanding on the treatment facilities and disinfection procedures. Turbidity analysis, where required, shall be performed by a continuous recording turbidimeter.

(b) For uses requiring a level of quality no greater than that of primary effluent, samples shall be analyzed by an approved laboratory method of settleable solids.

(c) For uses requiring an adequately disinfected, oxidized wastewater, samples shall be analyzed by an approved laboratory method for coliform bacteria content.

(d) For uses requiring an adequately disinfected, oxidized, coagulated, clarified, filtered wastewater, samples shall be analyzed by approved laboratory methods for turbidity and coliform bacteria content.

Article 7. Engineering Report and Operational Requirements

60323. **Engineering Report.** (a) No person shall produce or supply reclaimed water for direct reuse from a proposed water reclamation plant unless he files an engineering report.

(b) The report shall be prepared by a properly qualified engineer registered in California and experienced in the field of wastewater treatment, and shall contain a description of the design of the proposed reclamation system. The report shall clearly indicate the means for compliance with these regulations and any other features specified by the regulatory agency.

(c) The report shall contain a contingency plan which will assure that no untreated or inadequately-treated wastewater will be delivered to the use area.

60325. **Personnel.** (a) Each reclamation plant shall be provided with a sufficient number of qualified personnel to operate the facility effectively so as to achieve the required level of treatment at all times.

(b) Qualified personnel shall be those meeting requirements established pursuant to Chapter 9 (commencing with Section 13625) of the Water Code.

60327. **Maintenance.** A preventive maintenance program shall be provided at each reclamation plant to ensure that all equipment is kept in a reliable operating condition.

60329. **Operating Records and Reports.** (a) Operating records shall be maintained at the reclamation plant or a central depository within the operating agency. These shall include: all analyses specified in the reclamation criteria; records of operational problems, plant and equipment breakdowns, and diversions to emergency storage or disposal; all corrective or preventive action taken.

(b) Process or equipment failures triggering an alarm shall be recorded and maintained as a separate record file. The recorded information shall include the time and cause of failure and corrective action taken.

(c) A monthly summary of operating records as specified under (a) of this section shall be filed monthly with the regulatory agency.

(d) Any discharge of untreated or partially treated wastewater to the use area, and the cessation of same, shall be reported immediately by telephone to the regulatory agency, the State Department of Health, and the local health officer.

60331. **Bypass.** There shall be no bypassing of untreated or partially treated wastewater from the reclamation plant or any intermediate unit processes to the point of use.

Article 8. General Requirements of Design

60333. **Flexibility of Design.** The design of process piping, equipment arrangement, and unit structures in the reclamation plant must allow for efficiency and convenience in operation and maintenance and provide flexibility of operation to permit the highest possible degree of treatment to be obtained under varying circumstances.

60335. **Alarms.** (a) Alarm devices required for various unit processes as specified in other sections of these regulations shall be installed to provide warning of:

(1) Loss of power from the normal power supply.
(2) Failure of a biological treatment process.
(3) Failure of a disinfection process.
(4) Failure of a coagulation process.
(5) Failure of a filtration process.
(6) Any other specific process failure for which warning is required by the regulatory agency.

(b) All required alarm devices shall be independent of the normal power supply of the reclamation plant.

(c) The person to be warned shall be the plant operator, superintendent, or any other responsible person designated by the management of the reclamation plant and capable of taking prompt corrective action.

(d) Individual alarm devices may be connected to a master alarm to sound at a location where it can be conveniently observed by the attendant. In case the reclamation plant is not attended full time, the alarm(s) shall be connected to sound at a police station, fire station or other full-time service unit with which arrangements have been made to alert the person in charge at times that the reclamation plant is unattended.

60337. **Power Supply.** The power supply shall be provided with one of the following reliability features:

(a) Alarm and standby power source.

(b) Alarm and automatically actuated short-term retention or disposal provisions as specified in Section 60341.

(c) Automatically actuated long-term storage or disposal provisions as specified in Section 60341.

Article 9. Alternative Reliability Requirements for Uses Permitting Primary Effluent

60339. Primary Treatment. Reclamation plants producing reclaimed water exclusively for uses for which primary effluent is permitted shall be provided with one of the following reliability features:

(a) Multiple primary treatment units capable of producing primary effluent with one unit not in operation.

(b) Long-term storage or disposal provisions as specified in Section 60341.

Article 10. Alternative Reliability Requirements for Uses Requiring Oxidized, Disinfected Wastewater or Oxidized, Coagulated, Clarified, Filtered, Disinfected Wastewater

60341. Emergency Storage or Disposal. (a) Where short-term retention or disposal provisions are used as a reliability feature, these shall consist of facilities reserved for the purpose of storing or disposing of untreated or partially treated wastewater for at least a 24-hour period. The facilities shall include all the necessary diversion devices, provisions for odor control, conduits, and pumping and pump back equipment. All of the equipment other than the pump back equipment shall be either independent of the normal power supply or provided with a standby power source.

(b) Where long-term storage or disposal provisions are used as a reliability feature, these shall consist of ponds, reservoirs, percolation areas, downstream sewers leading to other treatment or disposal facilities or any other facilities reserved for the purpose of emergency storage or disposal of untreated or partially treated wastewater. These facilities shall be of sufficient capacity to provide disposal or storage of wastewater for at least 20 days, and shall include all the necessary diversion works, provisions for odor and nuisance control, conduits, and pumping and pump back equipment. All of the equipment other than the pump back equipment shall be either independent of the normal power supply or provided with a standby power source.

(c) Diversion to a less demanding reuse is an acceptable alternative to emergency disposal of partially treated wastewater provided that the quality of the partially treated wastewater is suitable for the less demanding reuse.

(d) Subject to prior approval by the regulatory agency, diversion to a discharge point which requires lesser quality of wastewater is an acceptable alternative to emergency disposal of partially treated wastewater.

(e) Automatically actuated short-term retention or disposal provisions and automatically actuated long-term storage or disposal provisions shall include, in addition to provisions of (a), (b), (c), or (d) of this section, all the necessary sensors, instruments, valves and other devices to enable fully automatic diversion of untreated or partially treated wastewater to approved emergency storage or disposal in the event of failure of a treatment process, and a manual reset to prevent automatic restart until the failure is corrected.

60343. Primary Treatment. All primary treatment unit processes shall be provided with one of the following reliability features:

(a) Multiple primary treatment units capable of producing primary effluent with one unit not in operation.

(b) Standby primary treatment unit process.

(c) Long-term storage or disposal provisions.

60345. Biological Treatment. All biological treatment unit processes shall be provided with one of the following reliability features:

(a) Alarm and multiple biological treatment units capable of producing oxidized wastewater with one unit not in operation.

(b) Alarm, short-term retention or disposal provisions, and standby replacement equipment.

(c) Alarm and long-term storage or disposal provisions.

(d) Automatically actuated long-term storage or disposal provisions.

60347. Secondary Sedimentation. All secondary sedimentation unit processes shall be provided with one of the following reliability features:

(a) Multiple sedimentation units capable of treating the entire flow with one unit not in operation.

(b) Standby sedimentation unit process.

(c) Long-term storage or disposal provisions.

60349. Coagulation.

(a) All coagulation unit processes shall be provided with the following mandatory features for uninterrupted coagulant feed:

(1) Standby feeders,
(2) Adequate chemical storage and conveyance facilities,
(3) Adequate reserve chemical supply, and
(4) Automatic dosage control.

(b) All coagulation unit processes shall be provided with one of the following reliability features:

(1) Alarm and multiple coagulation units capable of treating the entire flow with one unit not in operation;

(2) Alarm, short-term retention or disposal provisions, and standby replacement equipment;

(3) Alarm and long-term storage or disposal provisions;

(4) Automatically actuated long-term storage or disposal provisions; or

(5) Alarm and standby coagulation process.

60351. Filtration. All filtration unit processes shall be provided with one of the following reliability features:

(a) Alarm and multiple filter units capable of treating the entire flow with one unit not in operation.

(b) Alarm, short-term retention or disposal provisions and standby replacement equipment.

(c) Alarm and long-term storage or disposal provisions.
(d) Automatically actuated long-term storage or disposal provisions.
(e) Alarm and standby filtration unit process.

60353. Disinfection.

(a) All disinfection unit processes where chlorine is used as the disinfectant shall be provided with the following features for uninterrupted chlorine feed:

(1) Standby chlorine supply,
(2) Manifold systems to connect chlorine cylinders,
(3) Chlorine scales, and
(4) Automatic devices for switching to full chlorine cylinders.

Automatic residual control of chlorine dosage, automatic measuring and recording of chlorine residual, and hydraulic performance studies may also be required.

(b) All disinfection unit processes where chlorine is used as the disinfectant shall be provided with one of the following reliability features:

(1) Alarm and standby chlorinator;
(2) Alarm, short-term retention or disposal provisions, and standby replacement equipment;
(3) Alarm and long-term storage or disposal provisions;
(4) Automatically actuated long-term storage or disposal provisions; or
(5) Alarm and multiple point chlorination, each with independent power source, separate chlorinator, and separate chlorine supply.

60355. Other Alternatives to Reliability Requirements. Other alternatives to reliability requirements set forth in Articles 8 to 10 may be accepted if the applicant demonstrates to the satisfaction of the State Department of Health that the proposed alternative will assure an equal degree of reliability.

Article 11. Other Methods of Treatment

60357. Other Methods of Treatment. Methods of treatment other than those included in this chapter and their reliability features may be accepted if the applicant demonstrates to the satisfaction of the State Department of Health that the methods of treatment and reliability features will assure an equal degree of treatment and reliability.

APPENDIX B

WATER AND WASTEWATER TREATMENT SYSTEM COSTS

COST SUMMARY

WASTEWATER TREATMENT SYSTEMS

SECONDARY TREATMENT

ADVANCED WASTEWATER TREATMENT

THE FOLLOWING 16 PROCESSES ARE COST COMPONENTS OF SECONDARY TREATMENT-ACT SLUDGE

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS**			
										THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
1 RAW WASTEWATER PUMPING	1.0	215	258	70	0.6	1030	0	0.0	13	37	10.1	3.70	12.95
1 RAW WASTEWATER PUMPING	5.0	720	864	269	1.4	1195	0	0.0	21	103	5.6	2.06	7.21
1 RAW WASTEWATER PUMPING	10.0	1284	1541	516	2.6	1458	0	0.0	33	178	4.9	1.78	6.23
1 RAW WASTEWATER PUMPING	25.0	2462	2954	1231	7.0	2308	0	0.0	67	346	3.8	1.38	4.84
1 RAW WASTEWATER PUMPING	50.0	3911	4693	2347	13.0	3648	0	0.0	120	563	3.1	1.13	3.94
2 AERATED GRIT CHAMBER	1.0	107	128	4	2.1	954	0	0.0	12	24	6.6	2.40	8.40
2 AERATED GRIT CHAMBER	5.0	201	241	19	3.0	1869	0	0.0	22	45	2.5	0.90	3.15
2 AERATED GRIT CHAMBER	10.0	312	374	36	4.4	3013	0	0.0	36	71	1.9	0.71	2.49
2 AERATED GRIT CHAMBER	25.0	558	670	79	10.0	6445	0	0.0	77	140	1.5	0.56	1.96
2 AERATED GRIT CHAMBER	50.0	826	991	136	18.0	12165	0	0.0	144	238	1.3	0.48	1.67
3 CIRCULAR PRIMARY CLARIFIER	1.0	160	192	10	0.5	287	0	0.0	4	22	6.0	2.20	7.70
3 CIRCULAR PRIMARY CLARIFIER	5.0	358	430	12	1.3	582	0	0.0	8	49	2.7	0.98	3.43
3 CIRCULAR PRIMARY CLARIFIER	10.0	715	858	24	2.6	1163	0	0.0	15	96	2.6	0.96	3.36
3 CIRCULAR PRIMARY CLARIFIER	25.0	1421	1705	31	5.4	2065	0	0.0	27	188	2.1	0.75	2.63
3 CIRCULAR PRIMARY CLARIFIER	50.0	2490	2988	42	9.3	3130	0	0.0	42	324	1.8	0.65	2.27
4 AERATION BASIN	1.0	165	198	0	0.0	0	0	0.0	0	19	5.2	1.90	6.65
4 AERATION BASIN	5.0	617	740	0	0.0	0	0	0.0	0	70	3.8	1.40	4.90
4 AERATION BASIN	10.0	1147	1376	0	0.0	0	0	0.0	0	130	3.6	1.30	4.55
4 AERATION BASIN	25.0	2497	2996	0	0.0	0	0	0.0	0	283	3.1	1.13	3.96
4 AERATION BASIN	50.0	3956	4747	0	0.0	0	0	0.0	0	448	2.5	0.90	3.14
5 MECHANICAL AERATION EQUIPMENT	1.0	135	162	400	5.3	1882	0	0.0	36	51	14.0	5.10	17.85
5 MECHANICAL AERATION EQUIPMENT	5.0	463	556	2000	8.6	3654	0	0.0	105	157	8.6	3.14	10.99
5 MECHANICAL AERATION EQUIPMENT	10.0	833	1000	4000	12.3	5659	0	0.0	189	283	7.8	2.83	9.91
5 MECHANICAL AERATION EQUIPMENT	25.0	1705	2046	10000	20.4	10271	0	0.0	423	616	6.8	2.46	8.62
5 MECHANICAL AERATION EQUIPMENT	50.0	2565	3078	20000	26.3	13279	0	0.0	759	1050	5.8	2.10	7.35
6 CIRCULAR SECONDARY CLARIFIER	1.0	177	212	10	0.6	313	0	0.0	4	24	6.6	2.40	8.40
6 CIRCULAR SECONDARY CLARIFIER	5.0	438	526	13	1.7	693	0	0.0	9	59	3.2	1.18	4.13
6 CIRCULAR SECONDARY CLARIFIER	10.0	876	1051	26	3.3	1385	0	0.0	18	117	3.2	1.17	4.10
6 CIRCULAR SECONDARY CLARIFIER	25.0	1792	2150	35	6.8	2470	0	0.0	33	236	2.6	0.94	3.30
6 CIRCULAR SECONDARY CLARIFIER	50.0	3396	4075	60	12.7	4393	0	0.0	58	443	2.4	0.89	3.10
7 CHLORINE FEED SYSTEMS	1.0	20	24	4	1.8	410	0	15.3	9	11	3.0	1.10	3.85
7 CHLORINE FEED SYSTEMS	5.0	57	68	11	2.4	749	0	76.3	27	33	1.8	0.66	2.31
7 CHLORINE FEED SYSTEMS	10.0	92	110	18	3.1	1129	0	152.4	48	58	1.6	0.58	2.03
7 CHLORINE FEED SYSTEMS	25.0	142	170	33	4.6	2020	0	381.1	110	126	1.4	0.50	1.76
7 CHLORINE FEED SYSTEMS	50.0	175	210	43	5.4	2907	0	761.9	203	223	1.2	0.45	1.56

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL	COST	FACTORS*	
										THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
8 CHLORINE CONTACT BASIN	1.0	29	35	0	0.0	0	0	0.0	0	3	0.8	0.30	1.05
8 CHLORINE CONTACT BASIN	5.0	88	106	0	0.0	0	0	0.0	0	10	0.5	0.20	0.70
8 CHLORINE CONTACT BASIN	10.0	149	179	0	0.0	0	0	0.0	0	17	0.5	0.17	0.59
8 CHLORINE CONTACT BASIN	25.0	263	316	0	0.0	0	0	0.0	0	30	0.3	0.12	0.42
8 CHLORINE CONTACT BASIN	50.0	410	492	0	0.0	0	0	0.0	0	46	0.3	0.09	0.32
9 RETURN ACT SLUDGE PUMPING	1.0	86	103	11	0.5	733	0	0.0	8	18	4.9	1.80	6.30
9 RETURN ACT SLUDGE PUMPING	5.0	203	244	43	0.9	921	0	0.0	11	34	1.9	0.68	2.38
9 RETURN ACT SLUDGE PUMPING	10.0	312	374	81	1.4	1154	0	0.0	15	50	1.4	0.50	1.75
9 RETURN ACT SLUDGE PUMPING	25.0	457	548	193	3.1	1691	0	0.0	26	78	0.9	0.31	1.09
9 RETURN ACT SLUDGE PUMPING	50.0	556	667	365	6.4	2168	0	0.0	39	102	0.6	0.20	0.71
10 WASTE SLUDGE PUMPING	1.0	64	77	0	1.3	108	0	0.0	2	9	2.5	0.90	3.15
10 WASTE SLUDGE PUMPING	5.0	141	169	1	1.8	128	0	0.0	3	19	1.0	0.38	1.33
10 WASTE SLUDGE PUMPING	10.0	216	259	2	2.4	151	0	0.0	4	28	0.8	0.28	0.98
10 WASTE SLUDGE PUMPING	25.0	331	397	5	4.3	216	0	0.0	7	44	0.5	0.18	0.62
10 WASTE SLUDGE PUMPING	50.0	359	431	10	7.3	306	0	0.0	11	52	0.3	0.10	0.36
11 GRAVITY THICKENER	1.0	67	80	3	0.1	300	0	0.0	3	11	3.0	1.10	3.85
11 GRAVITY THICKENER	5.0	142	170	6	0.2	606	0	0.0	6	22	1.2	0.44	1.54
11 GRAVITY THICKENER	10.0	164	197	6	0.3	623	0	0.0	7	26	0.7	0.26	0.91
11 GRAVITY THICKENER	25.0	227	272	8	0.5	676	0	0.0	8	34	0.4	0.14	0.48
11 GRAVITY THICKENER	50.0	321	385	10	0.8	765	0	0.0	9	45	0.2	0.09	0.32
12 FLOTATION THICKENER	1.0		PROCESS NOT INCLUDED FOR THIS PLANT CAPACITY										
12 FLOTATION THICKENER	5.0	239	287	214	0.1	919	0	0.0	16	43	2.4	0.86	3.01
12 FLOTATION THICKENER	10.0	292	350	396	0.2	1678	0	0.0	29	62	1.7	0.62	2.17
12 FLOTATION THICKENER	25.0	411	493	878	0.3	3643	0	0.0	63	110	1.2	0.44	1.54
12 FLOTATION THICKENER	50.0	615	738	1553	0.6	6271	0	0.0	110	180	1.0	0.36	1.26
13 ANAEROBIC DIGESTER	1.0	189	227	31	2.0	1093	2116	0.0	20	41	11.2	4.10	14.35
13 ANAEROBIC DIGESTER	5.0	506	607	156	3.7	1745	10580	0.0	58	115	6.3	2.30	8.05
13 ANAEROBIC DIGESTER	10.0	853	1024	313	5.6	2560	21160	0.0	104	201	5.5	2.01	7.03
13 ANAEROBIC DIGESTER	25.0	1661	1993	782	10.1	4991	52900	0.0	242	430	4.7	1.72	6.02
13 ANAEROBIC DIGESTER	50.0	2859	3431	1563	14.9	8934	105800	0.0	469	793	4.3	1.59	5.55
14 SAND DRYING BEDS	1.0	77	92	0	2.6	688	0	0.0	9	18	4.9	1.80	6.30
14 SAND DRYING BEDS	5.0	352	422	0	13.0	3854	0	0.0	52	92	5.0	1.84	6.44
14 SAND DRYING BEDS	10.0	683	820	0	26.0	9329	0	0.0	119	196	5.4	1.96	6.86
14 SAND DRYING BEDS	25.0	1619	1943	0	65.1	29793	0	0.0	363	546	6.0	2.18	7.64
14 SAND DRYING BEDS	50.0	3250	3900	0	130.1	39901	0	0.0	529	897	4.9	1.79	6.28

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS* THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
15 SLUDGE HAULING	1.0	0	0	0	0.7	102	0	0.0	2	2	0.5	0.20	0.70
15 SLUDGE HAULING	5.0	0	0	0	1.7	408	0	0.0	6	6	0.3	0.12	0.42
15 SLUDGE HAULING	10.0	0	0	0	3.1	799	0	0.0	11	11	0.3	0.11	0.39
15 SLUDGE HAULING	25.0	0	0	0	7.3	2024	0	0.0	28	28	0.3	0.11	0.39
15 SLUDGE HAULING	50.0	0	0	0	14.5	4172	0	0.0	56	56	0.3	0.11	0.39
16 YARD MAINTENANCE	1.0	0	0	0	1.6	2100	0	0.0	23	23	6.3	2.30	8.05
16 YARD MAINTENANCE	5.0	0	0	0	1.9	2385	0	0.0	26	26	1.4	0.52	1.82
16 YARD MAINTENANCE	10.0	0	0	0	2.5	2985	0	0.0	32	32	0.9	0.32	1.12
16 YARD MAINTENANCE	25.0	0	0	0	4.1	4557	0	0.0	50	50	0.5	0.20	0.70
16 YARD MAINTENANCE	50.0	0	0	0	5.2	6311	0	0.0	68	68	0.4	0.14	0.48
TOTAL COST FOR COMPONENTS 1 THRU 16! SECONDARY TREATMENT-ACT SLUDGE													
SECONDARY TREATMENT-ACT SLUDGE	1.0	1710	2050	543	19.5	10000	2116	15.3	145	313	85.8	31.30	109.55
SECONDARY TREATMENT-ACT SLUDGE	5.0	5197	6239	2744	41.7	19708	10580	76.3	370	883	48.4	17.66	61.81
SECONDARY TREATMENT-ACT SLUDGE	10.0	9109	10934	5418	69.9	33086	21160	152.4	660	1556	42.6	15.56	54.46
SECONDARY TREATMENT-ACT SLUDGE	25.0	17871	21443	13275	149.0	73170	52900	381.1	1524	3285	36.0	13.14	45.99
SECONDARY TREATMENT-ACT SLUDGE	50.0	29535	35443	26129	264.6	108350	105800	761.9	2617	5528	30.3	11.06	38.70
THE FOLLOWING 7 PROCESSES ARE COST COMPONENTS OF MIXED MEDIA FILTRATION-SEC EFF													
17 GRAVITY FILTRATION STRUCTURE	1.0	175	210	15	1.6	1904	0	0.0	21	41	11.2	4.10	14.35
17 GRAVITY FILTRATION STRUCTURE	5.0	545	654	48	6.0	2422	0	0.0	32	94	5.2	1.88	6.58
17 GRAVITY FILTRATION STRUCTURE	10.0	956	1147	87	11.0	3127	0	0.0	45	153	4.2	1.53	5.36
17 GRAVITY FILTRATION STRUCTURE	25.0	1919	2303	184	23.5	5621	0	0.0	85	302	3.3	1.21	4.23
17 GRAVITY FILTRATION STRUCTURE	50.0	2896	3475	297	38.2	10710	0	0.0	154	482	2.6	0.96	3.37
18 FILTRA-HYDRAULIC SURFACE WASH	1.0	12	14	4	0.0	56	0	0.0	1	2	0.5	0.20	0.70
18 FILTRA-HYDRAULIC SURFACE WASH	5.0	39	47	17	0.0	175	0	0.0	2	6	0.3	0.12	0.42
18 FILTRA-HYDRAULIC SURFACE WASH	10.0	62	74	33	0.0	241	0	0.0	3	10	0.3	0.10	0.35
18 FILTRA-HYDRAULIC SURFACE WASH	25.0	117	140	81	0.1	312	0	0.0	6	19	0.2	0.08	0.27
18 FILTRA-HYDRAULIC SURFACE WASH	50.0	211	253	162	0.1	375	0	0.0	9	33	0.2	0.07	0.23
19 FILTRA-BACKWASH PUMPING SYSTEM	1.0	93	112	6	0.0	6	0	0.0	0	11	3.0	1.10	3.85
19 FILTRA-BACKWASH PUMPING SYSTEM	5.0	368	442	28	0.1	18	0	0.0	1	43	2.4	0.86	3.01
19 FILTRA-BACKWASH PUMPING SYSTEM	10.0	601	721	55	0.2	26	0	0.0	2	70	1.9	0.70	2.45
19 FILTRA-BACKWASH PUMPING SYSTEM	25.0	960	1152	138	0.4	40	0	0.0	5	114	1.2	0.46	1.60
19 FILTRA-BACKWASH PUMPING SYSTEM	50.0	1441	1729	277	0.7	57	0	0.0	10	173	0.9	0.35	1.21

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS* THOU $			
										THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
20 MEDIA-MIXED MEDIA FILTRATION	1.0	11	13	0	0.0	0	0	0.0	0	1	0.3	0.10	0.35
20 MEDIA-MIXED MEDIA FILTRATION	5.0	37	44	0	0.0	0	0	0.0	0	4	0.2	0.08	0.28
20 MEDIA-MIXED MEDIA FILTRATION	10.0	68	82	0	0.0	0	0	0.0	0	8	0.2	0.08	0.28
20 MEDIA-MIXED MEDIA FILTRATION	25.0	152	182	0	0.0	0	0	0.0	0	17	0.2	0.07	0.24
20 MEDIA-MIXED MEDIA FILTRATION	50.0	273	328	0	0.0	0	0	0.0	0	31	0.2	0.06	0.22
21 SUPPLY PUMPING	1.0	30	36	45	0.3	520	0	0.0	7	10	2.7	1.00	3.50
21 SUPPLY PUMPING	5.0	47	56	226	0.9	623	0	0.0	14	19	1.0	0.38	1.33
21 SUPPLY PUMPING	10.0	69	83	451	1.6	747	0	0.0	23	31	0.8	0.31	1.09
21 SUPPLY PUMPING	25.0	132	158	1128	3.7	1096	0	0.0	49	64	0.7	0.26	0.90
21 SUPPLY PUMPING	50.0	234	281	2254	7.6	1618	0	0.0	91	118	0.6	0.24	0.83
22 POLYMER FEED SYSTEMS	1.0	22	26	23	0.2	198	0	0.2	4	6	1.6	0.60	2.10
22 POLYMER FEED SYSTEMS	5.0	23	28	23	0.2	198	0	0.8	6	9	0.5	0.18	0.63
22 POLYMER FEED SYSTEMS	10.0	26	31	23	0.3	199	0	1.5	9	12	0.3	0.12	0.42
22 POLYMER FEED SYSTEMS	25.0	33	40	23	0.3	201	0	3.8	18	22	0.2	0.09	0.31
22 POLYMER FEED SYSTEMS	50.0	67	80	46	0.6	403	0	7.6	36	44	0.2	0.09	0.31
23 ALUM FEED SYSTEM	1.0	22	26	9	0.2	284	0	15.3	4	6	1.6	0.60	2.10
23 ALUM FEED SYSTEM	5.0	31	37	10	0.2	293	0	76.2	9	12	0.7	0.24	0.84
23 ALUM FEED SYSTEM	10.0	41	49	11	0.2	304	0	152.4	15	20	0.5	0.20	0.70
23 ALUM FEED SYSTEM	25.0	69	83	15	0.2	341	0	381.1	33	41	0.4	0.16	0.57
23 ALUM FEED SYSTEM	50.0	106	127	21	0.2	405	0	762.1	62	74	0.4	0.15	0.52

TOTAL COST FOR COMPONENTS 17 THRU 23: MIXED MEDIA FILTRATION-SEC EFF

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
MIXED MEDIA FILTRATION-SEC EFF	1.0	416	498	102	2.3	2968	0	15.5	37	77	21.1	7.70	26.95
MIXED MEDIA FILTRATION-SEC EFF	5.0	1250	1502	352	7.4	3729	0	77.0	64	187	10.2	3.74	13.09
MIXED MEDIA FILTRATION-SEC EFF	10.0	2094	2513	660	13.2	4644	0	153.9	97	304	8.3	3.04	10.64
MIXED MEDIA FILTRATION-SEC EFF	25.0	3885	4664	1569	28.1	7611	0	384.9	196	579	6.3	2.32	8.11
MIXED MEDIA FILTRATION-SEC EFF	50.0	6009	7212	3057	47.4	13568	0	769.7	362	955	5.2	1.91	6.69

THE FOLLOWING 14 PROCESSES ARE COST COMPONENTS OF LIME CLARIFICATION

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
24 LIME FEEDING	1.0	98	118	20	1.2	1189	0	0.0	14	25	6.8	2.50	8.75
24 LIME FEEDING	5.0	136	163	20	1.2	1639	0	0.0	18	33	1.8	0.66	2.31
24 LIME FEEDING	10.0	164	197	21	1.2	2092	0	0.0	23	42	1.2	0.42	1.47
24 LIME FEEDING	25.0	173	208	27	1.3	2878	0	0.0	31	51	0.6	0.20	0.71
24 LIME FEEDING	50.0	177	212	45	1.6	3208	0	0.0	35	55	0.3	0.11	0.39

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL	COST	FACTORS*	
										THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
25 POLYMER FEED SYSTEMS	1.0	22	26	23	0.2	198	0	0.2	4	6	1.6	0.60	2.10
25 POLYMER FEED SYSTEMS	5.0	23	28	23	0.2	198	0	0.8	6	9	0.5	0.18	0.63
25 POLYMER FEED SYSTEMS	10.0	26	31	23	0.3	199	0	1.5	9	12	0.3	0.12	0.42
25 POLYMER FEED SYSTEMS	25.0	33	40	23	0.3	201	0	3.8	18	22	0.2	0.09	0.31
25 POLYMER FEED SYSTEMS	50.0	67	80	46	0.6	403	0	7.6	36	44	0.2	0.09	0.31
26 RAPID MIX	1.0	10	12	32	0.2	470	0	0.0	6	7	1.9	0.70	2.45
26 RAPID MIX	5.0	22	26	157	0.5	468	0	0.0	10	12	0.7	0.24	0.84
26 RAPID MIX	10.0	37	44	315	0.8	469	0	0.0	15	19	0.5	0.19	0.66
26 RAPID MIX	25.0	80	96	787	1.8	499	0	0.0	30	39	0.4	0.16	0.55
26 RAPID MIX	50.0	150	180	1574	3.3	617	0	0.0	57	74	0.4	0.15	0.52
27 FLOCCULATION	1.0	41	49	9	0.4	105	0	0.0	2	7	1.9	0.70	2.45
27 FLOCCULATION	5.0	111	133	47	1.0	161	0	0.0	4	17	0.9	0.34	1.19
27 FLOCCULATION	10.0	187	224	94	1.8	218	0	0.0	7	28	0.8	0.28	0.98
27 FLOCCULATION	25.0	342	410	234	3.5	312	0	0.0	14	53	0.6	0.21	0.74
27 FLOCCULATION	50.0	417	500	468	5.3	349	0	0.0	23	70	0.4	0.14	0.49
28 CIRCULAR CLARIFIER	1.0	152	182	10	0.5	274	0	0.0	3	20	5.5	2.00	7.00
28 CIRCULAR CLARIFIER	5.0	319	383	11	1.2	527	0	0.0	7	43	2.4	0.86	3.01
28 CIRCULAR CLARIFIER	10.0	521	625	14	2.0	802	0	0.0	10	69	1.9	0.69	2.42
28 CIRCULAR CLARIFIER	25.0	1240	1488	29	4.7	1851	0	0.0	24	164	1.8	0.66	2.30
28 CIRCULAR CLARIFIER	50.0	2172	2606	39	8.2	2844	0	0.0	38	284	1.6	0.57	1.99
29 RECARBONATION BASIN	1.0	19	23	0	0.0	0	0	0.0	0	2	0.5	0.20	0.70
29 RECARBONATION BASIN	5.0	56	67	0	0.0	0	0	0.0	0	6	0.3	0.12	0.42
29 RECARBONATION BASIN	10.0	85	102	0	0.0	0	0	0.0	0	10	0.3	0.10	0.35
29 RECARBONATION BASIN	25.0	148	178	0	0.0	0	0	0.0	0	17	0.2	0.07	0.24
29 RECARBONATION BASIN	50.0	297	356	0	0.0	0	0	0.0	0	34	0.2	0.07	0.24
30 RECARB WITH SUBMERGED BURNERS	1.0	137	164	285	4.1	160	13815	0.0	56	71	19.5	7.10	24.85
30 RECARB WITH SUBMERGED BURNERS	5.0		PROCESS NOT INCLUDED FOR THIS PLANT CAPACITY										
30 RECARB WITH SUBMERGED BURNERS	10.0		PROCESS NOT INCLUDED FOR THIS PLANT CAPACITY										
30 RECARB WITH SUBMERGED BURNERS	25.0		PROCESS NOT INCLUDED FOR THIS PLANT CAPACITY										
30 RECARB WITH SUBMERGED BURNERS	50.0		PROCESS NOT INCLUDED FOR THIS PLANT CAPACITY										
31 RECARB WITH STACK GAS	1.0		PROCESS NOT INCLUDED FOR THIS PLANT CAPACITY										
31 RECARB WITH STACK GAS	5.0	77	92	2542	4.2	333	0	0.0	84	93	5.1	1.86	6.51
31 RECARB WITH STACK GAS	10.0	155	186	5084	6.2	558	0	0.0	164	182	5.0	1.82	6.37
31 RECARB WITH STACK GAS	25.0	389	467	12707	10.1	1014	0	0.0	401	445	4.9	1.78	6.23
31 RECARB WITH STACK GAS	50.0	773	928	25419	13.3	1631	0	0.0	792	880	4.8	1.76	6.16

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS** THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
32 RECTANGULAR CLARIFIERS	1.0	44	53	3	0.3	177	0	0.0	2	7	1.9	0.70	2.45
32 RECTANGULAR CLARIFIERS	5.0	160	192	8	0.8	434	0	0.0	5	23	1.3	0.46	1.61
32 RECTANGULAR CLARIFIERS	10.0	263	316	10	1.0	569	0	0.0	7	37	1.0	0.37	1.30
32 RECTANGULAR CLARIFIERS	25.0	535	642	21	2.1	939	0	0.0	12	73	0.8	0.29	1.02
32 RECTANGULAR CLARIFIERS	50.0	1070	1284	42	4.1	1877	0	0.0	24	145	0.8	0.29	1.02
33 CHEMICAL SLUDGE PUMPING-DILUTE	1.0	51	61	1	2.5	84	0	0.0	3	9	2.5	0.90	3.15
33 CHEMICAL SLUDGE PUMPING-DILUTE	5.0	74	89	7	3.4	142	0	0.0	5	13	0.7	0.26	0.91
33 CHEMICAL SLUDGE PUMPING-DILUTE	10.0	102	122	13	4.1	177	0	0.0	6	18	0.5	0.18	0.63
33 CHEMICAL SLUDGE PUMPING-DILUTE	25.0	166	199	33	5.8	275	0	0.0	10	29	0.3	0.12	0.41
33 CHEMICAL SLUDGE PUMPING-DILUTE	50.0	218	262	66	8.5	412	0	0.0	15	40	0.2	0.08	0.28
34 GRAVITY THICKENER	1.0	65	78	3	0.1	298	0	0.0	3	10	2.7	1.00	3.50
34 GRAVITY THICKENER	5.0	70	84	3	0.1	302	0	0.0	3	11	0.6	0.22	0.77
34 GRAVITY THICKENER	10.0	80	96	3	0.1	310	0	0.0	3	12	0.3	0.12	0.42
34 GRAVITY THICKENER	25.0	171	205	6	0.3	629	0	0.0	7	26	0.3	0.10	0.36
34 GRAVITY THICKENER	50.0	219	263	8	0.5	669	0	0.0	7	32	0.2	0.06	0.22
35 DECANTER CENTRIFUGE	1.0	150	180	38	1.5	729	0	0.0	10	27	7.4	2.70	9.45
35 DECANTER CENTRIFUGE	5.0	156	187	45	1.7	772	0	0.0	11	29	1.6	0.58	2.03
35 DECANTER CENTRIFUGE	10.0	179	215	71	2.6	936	0	0.0	14	34	0.9	0.34	1.19
35 DECANTER CENTRIFUGE	25.0	241	289	146	5.2	1383	0	0.0	23	50	0.5	0.20	0.70
35 DECANTER CENTRIFUGE	50.0	313	376	252	8.3	1906	0	0.0	35	70	0.4	0.14	0.49
36 MULTIPLE HEARTH RECALCINATION	1.0	PROCESS NOT INCLUDED FOR THIS PLANT CAPACITY											
36 MULTIPLE HEARTH RECALCINATION	5.0	1220	1464	301	5.6	2708	25903	0.0	119	257	14.1	5.14	17.99
36 MULTIPLE HEARTH RECALCINATION	10.0	1590	1908	421	7.9	4188	34334	0.0	165	345	9.5	3.45	12.08
36 MULTIPLE HEARTH RECALCINATION	25.0	2556	3067	688	13.9	7966	66490	0.0	314	604	6.6	2.42	8.46
36 MULTIPLE HEARTH RECALCINATION	50.0	3682	4418	1025	22.0	12539	138002	0.0	592	1009	5.5	2.02	7.06
37 SLUDGE HAULING	1.0	0	0	0	0.9	163	0	0.0	2	2	0.5	0.20	0.70
37 SLUDGE HAULING	5.0	0	0	0	1.0	198	0	0.0	3	3	0.2	0.06	0.21
37 SLUDGE HAULING	10.0	0	0	0	1.6	371	0	0.0	5	5	0.1	0.05	0.18
37 SLUDGE HAULING	25.0	0	0	0	3.4	903	0	0.0	12	12	0.1	0.05	0.17
37 SLUDGE HAULING	50.0	0	0	0	6.6	1824	0	0.0	25	25	0.1	0.05	0.18
TOTAL COST FOR COMPONENTS 24 THRU 37: LIME CLARIFICATION													
LIME CLARIFICATION	1.0	901	1082	424	11.9	3847	13815	0.2	105	193	52.9	19.30	67.55
LIME CLARIFICATION	5.0	2783	3338	3164	21.1	7882	25903	0.8	275	549	30.1	10.98	38.43
LIME CLARIFICATION	10.0	3892	4670	6069	29.6	10889	34334	1.5	428	813	22.3	8.13	28.45
LIME CLARIFICATION	25.0	6980	8378	14701	52.4	18850	66490	3.8	896	1585	17.4	6.34	22.19
LIME CLARIFICATION	50.0	10981	13180	28984	82.4	28279	138002	7.6	1679	2762	15.1	5.52	19.33

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS*			
										THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
THE FOLLOWING 7 PROCESSES ARE COST COMPONENTS OF MIXED MEDIA FILTRATION-AWT													
38 GRAVITY FILTRATION STRUCTURE	1.0	136	163	11	1.1	1856	0	0.0	20	35	9.6	3.50	12.25
38 GRAVITY FILTRATION STRUCTURE	5.0	364	437	32	3.8	2157	0	0.0	26	67	3.7	1.34	4.69
38 GRAVITY FILTRATION STRUCTURE	10.0	631	757	56	7.0	2558	0	0.0	34	105	2.9	1.05	3.67
38 GRAVITY FILTRATION STRUCTURE	25.0	1321	1585	122	15.6	3903	0	0.0	58	208	2.3	0.83	2.91
38 GRAVITY FILTRATION STRUCTURE	50.0	2165	2598	211	26.9	6560	0	0.0	99	344	1.9	0.69	2.41
39 FILTRA-HYDRAULIC SURFACE WASH	1.0	11	13	2	0.0	54	0	0.0	1	2	0.5	0.20	0.70
39 FILTRA-HYDRAULIC SURFACE WASH	5.0	25	30	10	0.0	115	0	0.0	1	4	0.2	0.08	0.28
39 FILTRA-HYDRAULIC SURFACE WASH	10.0	42	50	20	0.0	178	0	0.0	2	7	0.2	0.07	0.25
39 FILTRA-HYDRAULIC SURFACE WASH	25.0	77	92	49	0.0	248	0	0.0	4	13	0.1	0.05	0.18
39 FILTRA-HYDRAULIC SURFACE WASH	50.0	135	162	97	0.1	311	0	0.0	6	21	0.1	0.04	0.15
40 FILTRA-BACKWASH PUMPING SYSTEM	1.0	71	85	3	0.0	5	0	0.0	0	8	2.2	0.80	2.80
40 FILTRA-BACKWASH PUMPING SYSTEM	5.0	232	278	17	0.1	12	0	0.0	1	27	1.5	0.54	1.89
40 FILTRA-BACKWASH PUMPING SYSTEM	10.0	404	485	33	0.1	19	0	0.0	1	47	1.3	0.47	1.65
40 FILTRA-BACKWASH PUMPING SYSTEM	25.0	707	848	83	0.2	29	0	0.0	3	83	0.9	0.33	1.16
40 FILTRA-BACKWASH PUMPING SYSTEM	50.0	1009	1211	166	0.4	43	0	0.0	6	120	0.7	0.24	0.84
41 MEDIA-MIXED MEDIA FILTRATION	1.0	8	10	0	0.0	0	0	0.0	0	1	0.3	0.10	0.35
41 MEDIA-MIXED MEDIA FILTRATION	5.0	24	29	0	0.0	0	0	0.0	0	3	0.2	0.06	0.21
41 MEDIA-MIXED MEDIA FILTRATION	10.0	44	53	0	0.0	0	0	0.0	0	5	0.1	0.05	0.18
41 MEDIA-MIXED MEDIA FILTRATION	25.0	98	118	0	0.0	0	0	0.0	0	11	0.1	0.04	0.15
41 MEDIA-MIXED MEDIA FILTRATION	50.0	178	214	0	0.0	0	0	0.0	0	20	0.1	0.04	0.14
42 SUPPLY PUMPING	1.0	30	36	45	0.3	520	0	0.0	7	10	2.7	1.00	3.50
42 SUPPLY PUMPING	5.0	47	56	226	0.9	623	0	0.0	14	19	1.0	0.38	1.33
42 SUPPLY PUMPING	10.0	69	83	451	1.6	747	0	0.0	23	31	0.8	0.31	1.09
42 SUPPLY PUMPING	25.0	132	158	1128	3.7	1096	0	0.0	49	64	0.7	0.26	0.90
42 SUPPLY PUMPING	50.0	234	281	2254	7.6	1618	0	0.0	91	118	0.6	0.24	0.83
43 POLYMER FEED SYSTEMS	1.0	22	26	23	0.2	198	0	0.2	4	6	1.6	0.60	2.10
43 POLYMER FEED SYSTEMS	5.0	23	28	23	0.2	198	0	0.8	6	9	0.5	0.18	0.63
43 POLYMER FEED SYSTEMS	10.0	26	31	23	0.3	199	0	1.5	9	12	0.3	0.12	0.42
43 POLYMER FEED SYSTEMS	25.0	33	40	23	0.3	201	0	3.8	18	22	0.2	0.09	0.31
43 POLYMER FEED SYSTEMS	50.0	67	80	46	0.6	403	0	7.6	36	44	0.2	0.09	0.31
44 ALUM FEED SYSTEM	1.0	22	26	9	0.2	284	0	15.3	4	6	1.6	0.60	2.10
44 ALUM FEED SYSTEM	5.0	31	37	10	0.2	293	0	76.2	9	12	0.7	0.24	0.84
44 ALUM FEED SYSTEM	10.0	41	49	11	0.2	304	0	152.4	15	20	0.5	0.20	0.70
44 ALUM FEED SYSTEM	25.0	69	83	15	0.2	341	0	381.1	33	41	0.4	0.16	0.57
44 ALUM FEED SYSTEM	50.0	106	127	21	0.2	405	0	762.1	62	74	0.4	0.15	0.52

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL	COST	FACTORS*	
										THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
TOTAL COST FOR COMPONENTS 38 THRU 44: MIXED MEDIA FILTRATION-AWT													
MIXED MEDIA FILTRATION-AWT	1.0	342	408	93	1.9	2917	0	15.5	36	68	18.6	6.80	23.80
MIXED MEDIA FILTRATION-AWT	5.0	854	1026	318	5.2	3398	0	77.0	57	141	7.7	2.82	9.87
MIXED MEDIA FILTRATION-AWT	10.0	1442	1730	594	9.1	4005	0	153.9	84	227	6.2	2.27	7.95
MIXED MEDIA FILTRATION-AWT	25.0	2799	3359	1420	20.1	5818	0	384.9	165	442	4.8	1.77	6.19
MIXED MEDIA FILTRATION-AWT	50.0	4475	5372	2795	35.8	9340	0	769.7	300	741	4.1	1.48	5.19
THE FOLLOWING 3 PROCESSES ARE COST COMPONENTS OF ACTIVATED CARBON ADSORPTION													
45 UPFLOW GRAN CARBON CONTACTORS	1.0	276	331	123	1.5	2001	0	0.0	25	56	15.3	5.60	19.60
45 UPFLOW GRAN CARBON CONTACTORS	5.0	1332	1598	222	4.3	2640	0	0.0	37	188	10.3	3.76	13.16
45 UPFLOW GRAN CARBON CONTACTORS	10.0	2594	3113	348	7.7	3406	0	0.0	52	346	9.5	3.46	12.11
45 UPFLOW GRAN CARBON CONTACTORS	25.0	6069	7283	746	17.6	5501	0	0.0	95	782	8.6	3.13	10.95
45 UPFLOW GRAN CARBON CONTACTORS	50.0	11306	13567	1470	33.2	8479	0	0.0	162	1443	7.9	2.89	10.10
46 GRANULAR ACTIVATED CARBON	1.0	49	59	0	0.0	0	0	0.0	0	6	1.6	0.60	2.10
46 GRANULAR ACTIVATED CARBON	5.0	239	287	0	0.0	0	0	0.0	0	27	1.5	0.54	1.89
46 GRANULAR ACTIVATED CARBON	10.0	475	570	0	0.0	0	0	0.0	0	54	1.5	0.54	1.89
46 GRANULAR ACTIVATED CARBON	25.0	1169	1403	0	0.0	0	0	0.0	0	132	1.4	0.53	1.85
46 GRANULAR ACTIVATED CARBON	50.0	2278	2734	0	0.0	0	0	0.0	0	258	1.4	0.52	1.81
47 GRAN ACT CARBON REGENERATION	1.0	577	692	182	1.8	410	1508	4.6	22	87	23.8	8.70	30.45
47 GRAN ACT CARBON REGENERATION	5.0	895	1074	261	3.9	1380	6400	22.8	74	175	9.6	3.50	12.25
47 GRAN ACT CARBON REGENERATION	10.0	1262	1514	297	5.1	2585	11549	45.6	134	277	7.6	2.77	9.70
47 GRAN ACT CARBON REGENERATION	25.0	2015	2418	401	7.8	5560	26245	114.1	302	530	5.8	2.12	7.42
47 GRAN ACT CARBON REGENERATION	50.0	2581	3097	560	10.0	8880	48933	228.1	559	851	4.7	1.70	5.96
TOTAL COST FOR COMPONENTS 45 THRU 47: ACTIVATED CARBON ADSORPTION													
ACTIVATED CARBON ADSORPTION	1.0	1036	1242	305	3.3	2411	1508	4.6	47	149	40.8	14.90	52.15
ACTIVATED CARBON ADSORPTION	5.0	2834	3402	483	8.2	4020	6400	22.8	111	390	21.4	7.80	27.30
ACTIVATED CARBON ADSORPTION	10.0	4980	5975	645	12.8	5991	11549	45.6	186	677	18.5	6.77	23.70
ACTIVATED CARBON ADSORPTION	25.0	10640	12768	1147	25.4	11061	26245	114.1	397	1444	15.8	5.78	20.22
ACTIVATED CARBON ADSORPTION	50.0	18588	22307	2030	43.2	17350	48933	228.1	721	2552	14.0	5.10	17.86
***** TREATMENT SYSTEM COST SUMMARIES INCLUDING YARD PIPING AT 15 PERCENT OF CONSTRUCTION COST *****													
SECONDARY TREATMENT-ACT SLUDGE	1.0	1710	2050	543	19.5	10000	2116	15.3	145	313	85.8	31.30	109.55
SECONDARY TREATMENT-ACT SLUDGE	5.0	5197	6239	2744	41.7	19708	10580	76.3	370	883	48.4	17.66	61.81
SECONDARY TREATMENT-ACT SLUDGE	10.0	9109	10934	5418	69.9	33086	21160	152.4	660	1556	42.6	15.56	54.46
SECONDARY TREATMENT-ACT SLUDGE	25.0	17871	21443	13275	149.0	73170	52900	381.1	1524	3285	36.0	13.14	45.99
SECONDARY TREATMENT-ACT SLUDGE	50.0	29535	35443	26129	264.6	108350	105800	761.9	2617	5528	30.3	11.06	38.70

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS*			
										THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
ADVANCED WASTEWATER TREATMENT	1.0	3989	4782	1365	36.6	19175	17439	35.5	333	723	198.1	72.30	253.05
ADVANCED WASTEWATER TREATMENT	5.0	11668	14005	6709	76.2	35008	42883	176.8	813	1963	107.6	39.26	137.41
ADVANCED WASTEWATER TREATMENT	10.0	19423	23309	12726	121.5	53971	67043	353.5	1358	3273	89.7	32.73	114.56
ADVANCED WASTEWATER TREATMENT	25.0	38290	45948	30543	246.8	108899	145635	883.8	2982	6756	74.0	27.02	94.58
ADVANCED WASTEWATER TREATMENT	50.0	63579	76302	59938	426.1	163328	292735	1767.4	5317	11583	63.5	23.17	81.08

DESIGN CRITERIA AND UNIT PROCESS SIZES

PROCESS OR COMPONENT	DESIGN FLOW,MGD					
	AVERAGE:	1.0	5.0	10.0	25.0	50.0
	PEAK:	2.0	10.0	20.0	45.0	80.0
1 RAW WASTEWATER PUMPING, FIRM CAPACITY, MGD		2.0	10.0	20.0	45.0	80.0
FIRM CAPACITY EQUIVALENT TO PEAK DESIGN FLOW						
2 AERATED GRIT CHAMBER, VOLUME, CU FT		464.0	2321.0	4642.0	10445.0	18568.0
DETENTION TIME = 2.5 MINUTES AT PEAK DESIGN FLOW						
3 CIRCULAR PRIMARY CLARIFIER, SURFACE AREA/UNIT, SQ FT		625.0	3125.0	3125.0	7815.0	15625.0
NUMBER OF UNITS		2	2	4	4	4
OVERFLOW RATE = 800 GAL/DAY/SQ FT						
4 AERATION BASIN, VOLUME, CU FT		44600.0	223000.0	446000.0	1115000.0	2230000.0
HYDRAULIC DETENTION TIME = 8 HRS						
5 MECHANICAL AERATION EQUIPMENT, INSTALLED HORSEPOWER		80.0	400.0	800.0	2000.0	4000.0
MAXIMUM OXYGEN UPTAKE RATE = 70 MG/L/HR						
6 CIRCULAR SECONDARY CLARIFIER, SURFACE AREA/UNIT, SQ FT		833.0	4167.0	4167.0	10419.0	13891.0
NUMBER OF UNITS		2	2	4	4	6
OVERFLOW RATE = 600 GAL/DAY/SQ FT						
7 CHLORINE FEED SYSTEMS, FEED CAPACITY, LB/DAY		167.0	835.0	1670.0	3758.0	6680.0
SIZED FOR 10 MG/L DOSE AT PEAK DESIGN FLOW						
8 CHLORINE CONTACT BASIN, VOLUME, CU FT		5570.0	27852.0	55704.0	125334.0	222816.0
DETENTION TIME = 30 MINUTES AT PEAK DESIGN FLOW						
9 RETURN ACTIVATED SLUDGE PUMPING, FIRM CAPACITY, MGD		1.0	5.0	10.0	22.5	40.0
CAPACITY = 50 PER CENT OF PEAK DESIGN FLOW						
10 WASTE SLUDGE PUMPING, FIRM PUMPING CAPACITY, GPM		66.0	330.0	660.0	1650.0	3300.0
SIZED FOR INTERMITTENT OPERATION OF 10 MIN/HR AT AVE FLOW						
11 GRAVITY THICKENER, SURFACE AREA/UNIT, SQ FT		115.0	163.0	325.0	813.0	1625.0
NUMBER OF UNITS		1	2	2	2	2
SOLIDS LOADING = 20 LB/SQ FT/DAY FOR PRIMARY SLUDGE						
12 FLOTATION THICKENER, TOTAL SURFACE AREA, SQ FT		0.0	250.0	500.0	1250.0	2500.0
SOLIDS LOADING = 20 LB/SQ FT/DAY FOR WASTE ACTIVATED SLUDGE						
13 ANAEROBIC DIGESTER,VOLUME,CU FT,INCLUDES PRIMARY & SECONDARY		19850.0	99250.0	198500.0	496250.0	992500.0
TOTAL DETENTION TIME = 30 DAYS						
14 SAND DRYING BEDS, SURFACE AREA, SQ FT		22000.0	110000.0	220000.0	550000.0	1100000.0
SOLIDS LOADING = 25 LB/SQ FT/YEAR						
15 SLUDGE HAULING, ANNUAL VOLUME, CU YD		730.0	3650.0	7300.0	18250.0	36500.0
SLUDGE DRIED TO 45% SOLIDS ON SAND BEDS						
16 YARD MAINTENANCE, AREA OF PLANT SITE, SQ FT		271800.0	322000.0	435600.0	740500.0	1002000.0
AREA REQUIREMENTS ADAPTED FROM BLACK & VEATCH REPORT, 1971						

DESIGN CRITERIA AND UNIT PROCESS SIZES

PROCESS OR COMPONENT					
DESIGN FLOW,MGD AVERAGE: PEAK:	1.0 2.0	5.0 10.0	10.0 20.0	25.0 45.0	50.0 80.0
17 GRAVITY FILTRATION STRUCTURE, TOTAL FILTER AREA, SQ FT MIXED MEDIA FILTER, FILTRATION RATE = 3 GPM/SQ FT, SEC EFFL	231.0	1160.0	2310.0	5780.0	11600.0
18 FILTRA-HYDRAULIC SURFACE WASH,INDIVIDUAL FILTER AREA,SQ FT NUMBER OF UNITS MIXED MEDIA FILTER, FILTRATION RATE = 3 GPM/SQ FT, SEC EFFL	116.0 2	193.0 6	289.0 8	578.0 10	964.0 12
19 FILTRA-BACKWASH PUMPING SYSTEM, FIRM PUMPING CAPACITY, GPM NUMBER OF UNITS MIXED MEDIA FILTER, SEC EFFL, BACKWASH CAPACITY=18 GPM/SQ FT	2090.0 2	3470.0 6	5200.0 8	10400.0 10	17400.0 12
20 MEDIA-MIXED MEDIA FILTRATION, TOTAL FILTER AREA, SQ FT MIXED MEDIA FILTER, SEC EFFL, FILTRATION RATE = 3 GPM/SQ FT	231.0	1160.0	2310.0	5780.0	11600.0
21 SUPPLY PUMPING, PUMPING RATE, MGD GRAVITY FILTER OR AWT UPFLOW CARBON CONTACTOR SUPPLY	1.0	5.0	10.0	25.0	50.0
22 POLYMER FEED SYSTEMS, FEED CAPACITY/UNIT,LBS/DAY NUMBER OF UNITS FILTRATION AND COAGULANT AID,1 MG/L CAPACITY,0.1 MG/L AVG	8.3 1	42.0 1	83.0 1	208.0 1	208.0 2
23 ALUM FEED SYSTEM-DRY ALUM, CAPACITY, LBS/HR MIXED MEDIA FILTER AID, 20 MG/L CAPACITY, 10 MG/L AVG	7.0	34.8	69.6	174.0	348.0
24 LIME FEED SYSTEM, CAO FEED CAPACITY, LBS/HR SIZED FOR 300 MG/L DOSE AT PEAK FLOW	208.0	1040.0	2080.0	4690.0	8340.0
25 POLYMER FEED SYSTEM, FEED CAPACITY/UNIT, LBS/DAY NUMBER OF UNITS 1 MG/L CAPACITY, 0.1 MG/L AVG FEED RATE	8.3 1	42.0 1	83.0 1	208.0 1	208.0 2
26 RAPID MIX BASIN, VOLUME,CU FT NUMBER OF UNITS DETENTION TIME = 60 SEC AT AVG FLOW	93.0 1	464.0 1	928.0 1	2320.0 1	4640.0 1
27 FLOCCULATION BASIN, TOTAL VOLUME, CU FT HORIZONTAL PADDLE, G=80, DETENTION TIME=30 MIN AT AVG FLOW	2780.0	13900.0	27800.0	69500.0	139000.0
28 CIRCULAR CLARIFIER, SURFACE AREA/UNIT, SQ FT NUMBER OF UNITS OVERFLOW RATE = 950 GAL/DAY/SQ FT	526.0 2	2630.0 2	5260.0 2	6580.0 4	13200.0 4
29 RECARBONATION BASIN, VOLUME/UNIT, CU FT NUMBER OF UNITS 15 MIN DETENTION AT AVG FLOW	770.0 2	1740.0 4	3480.0 4	8700.0 4	8700.0 8
30 RECARBONATION-SUBMERGED BURNERS,CAPACITY/UNIT,LBS CO2/DAY NUMBER OF UNITS FOR 1 MGD PLANT ONLY, MAXIMUM FEED RATE = 525 MG/L CO2	2190.0 2	0.0 0	0.0 0	0.0 0	0.0 0

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          DESIGN CRITERIA AND UNIT PROCESS SIZES

 PROCESS OR COMPONENT                                   DESIGN FLOW,MGD
                                                           AVERAGE:        1.0         5.0        10.0        25.0        50.0
                                                              PEAK:        2.0        10.0        20.0        45.0        80.0

 31 RECARBONATION-STACK GAS, CAPACITY, LBS CO2/DAY                         0.0     21900.0     43800.0    110000.0    219000.0
    AVG FEED RATE = 350 MG/L, MAX RATE = 525 MG/L

 32 RECTANGULAR CLARIFIER, SURFACE AREA/UNIT, SQ FT                      333.0       833.0      1670.0      4170.0      4170.0
    NUMBER OF UNITS                                                          1           2           2           2           4
    RECARB-INTERMEDIATE SETTLING,OVERFLOW RATE=3000 GPD/SQ FT

 33 CHEMICAL SLUDGE PUMPING, FIRM PUMPING CAPACITY, GPM                   83.0       416.0       833.0      2080.0      4160.0
    SIZED FOR 600 MG/L DOSE AND 0.5% SOLIDS,AVG=300 MG/L @ 1.0%

 34 GRAVITY THICKENER, SURFACE AREA/UNIT, SQ FT                           78.0       150.0       300.0       375.0       750.0
    NUMBER OF UNITS                                                          1           1           1           2           2
    LIME SLUDGE @ 1% SOLIDS, OVERFLOW RATE=1000 GPD/SQ FT

 35 DECANTER CENTRIFUGE, FEED CAPACITY, GPM                               10.0        13.0        25.0        63.0       125.0
    NUMBER OF UNITS                                                          1           1           1           1           1
    LIME SLUDGE, 8% SOLIDS AS INFLUENT

 36 MULTIPLE HEARTH RECALCINATION, EFFECTIVE HEARTH AREA,SQ FT             0.0       149.0       297.0       746.0      1490.0
    WET FEED OF 7.0 LB/SQ FT/HR AT 50% SOLIDS

 37 SLUDGE HAULING, ANNUAL VOLUME, CU  YD                               1320.0      1650.0      3300.0      8250.0     16500.0
    LIME SLUDGE AT 50% SOLIDS, 25% WASTED FOR PLANTS OVER 1 MGD

 38 GRAVITY FILTRATION STRUCTURE, TOTAL FILTER AREA, SQ FT               139.0       694.0      1390.0      3470.0      6940.0
    MIXED MEDIA FILTER, FILTRATION RATE=5 GPM/SQ FT, WATER & AWT

 39 FILTRA-HYDRAULIC SURFACE WASH, INDIVIDUAL FILTER AREA, SQ FT          69.0       174.0       231.0       434.0       694.0
    NUMBER OF UNITS                                                          2           4           6           8          10
    MIXED MEDIA FILTER, FILTRATION RATE=5 GPM/SQ FT, WATER & AWT

 40 FILTRA-BACKWASH PUMPING SYSTEM, FIRM PUMPING CAPACITY, GPM          1240.0      3130.0      4160.0      7810.0     12500.0
    NUMBER OF UNITS                                                          2           4           6           8          10
    MIXED MEDIA FILTER,WATER&AWT, BACKWASH CAPACITY=18 GPM/SQ FT

 41 MEDIA-MIXED MEDIA FILTRATION, TOTAL FILTER AREA, SQ FT               139.0       694.0      1390.0      3470.0      6940.0
    MIXED MEDIA FILTER, WATER & AWT, FILTRATION RATE=5 GPM/SQ FT

 42 SUPPLY PUMPING,PUMPING RATE, MGD                                       1.0         5.0        10.0        25.0        50.0
    GRAVITY FILTER OR AWT UPFLOW CARBON CONTACTOR SUPPLY

 43 POLYMER FEED SYSTEMS, FEED CAPACITY/UNIT, LBS/DAY                      8.3        42.0        83.0       208.0       208.0
    NUMBER OF UNITS                                                          1           1           1           1           2
    FILTRATION AND COAGULANT AID,1 MG/L CAPACITY,0.1 MG/L AVG

 44 ALUM FEED SYSTEM-DRY ALUM, CAPACITY, LBS/HR                            7.0        34.8        69.6       174.0       348.0
    MIXED MEDIA FILTER AID, 20 MG/L CAPACITY, 10 MG/L AVG

 45 UPFLOW GRAN CARBON CONTACTORS,  AVG FLOW, MGD                          1.0         5.0        10.0        25.0        50.0
    CONTACT TIME=30 MIN, HYDRAULIC LOADING = 5 GPM/SQ FT
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              DESIGN CRITERIA AND UNIT PROCESS SIZES

 PROCESS OR COMPONENT
                                            DESIGN FLOW,MGD
                                              AVERAGE:        1.0        5.0       10.0       25.0       50.0
                                              PEAK:           2.0       10.0       20.0       45.0       80.0

 46 GRANULAR ACTIVATED CARBON, TOTAL WEIGHT, LBS
    CONTACT TIME= 30 MIN, CARBON WEIGHT = 30 LB/CU FT     83600.0   418000.0   836000.0  2090000.0  4180000.0

 47 GRANULAR CARBON REGENERATION, HEARTH AREA, SQ FT
    40% DOWNTIME,40 LB/SQ FT/DAY; REMOVAL=0.5 LB COD/LB CARBON    27.0      104.0      208.0      521.0     1040.0


COST INFORMATION:


 COSTS PRESENTED AS DOLLARS ARE CURRENT AS OF JANUARY 1977

 CAPITAL COST FACTORS:  INTEREST RATE(%)    =7
                        NUMBER OF YEARS     =20
                        ENGINEERING(%)      =10    (PER CENT OF CONSTRUCTION COST)
                        LEGAL,FISCAL(%)     =3     (PER CENT OF CONSTRUCTION COST)
                        INT DURING CONST(%)=7      (PER CENT OF CONSTRUCTION COST)
                        YARD PIPING FACTOR =15     (PER CENT OF CONSTRUCTION COST)

 PER CAPITA COSTS:      GAL/PERSON/DAY      =100
                        PEOPLE/HOME         =3.5

 UNIT COST FACTORS:     ELECTRICITY,$/KWH  =0.03
                        LABOR,$/HR          =10
                        FUEL,$/MIL BTU      =3

 CHEMICAL COSTS:        LIME,$/TON          =52
                        ALUM,$/TON          =75
                        CHLORINE,$/TON      =220
                        POLYMER,$/LB        =2

 CONSTN COST INDEXES:   EXCAVATION          =220.6  (ENR SKILLED LABOR)
                        MANUFACTURED EQUIP =195.7  (BLS #114)
                        CONCRETE            =193.1  (BLS #132)
                        STEEL               =221.3  (BLS #101.3)
                        LABOR               =220.6  (ENR SKILLED LABOR)
                        PIPES & VALVES      =209.4  (BLS #114.901)
                        HOUSING             =30     (ACTUAL BLDG COST,$/SQ FT)
                        WHOLESALE PRICE     =188.0  (BLS ALL COMMODITIES)

 EPA CONSTN INDEXES:    SCCT(5 MGD PLANT)  =121    (NATIONAL INDEX VALUE)
                        LCAT(50 MGD PLANT) =132    (NATIONAL INDEX VALUE)
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COST SUMMARY

WATER TREATMENT SYSTEMS

CONVENTIONAL WATER TREATMENT

UPGRADED WATER TREATMENT

UPGRADED TREATMENT AND REVERSE OSMOSIS

THE FOLLOWING 12 PROCESSES ARE COST COMPONENTS OF CLARIFICATION AND CHLORINATION

										TOTAL ANNUAL COST FACTORS			
COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
1 RAW WATER PUMPING	1.0	148	178	70	0.6	1012	0	0.0	13	30	8.2	3.00	10.50
1 RAW WATER PUMPING	5.0	411	493	269	1.4	1087	0	0.0	20	67	3.7	1.34	4.69
1 RAW WATER PUMPING	10.0	724	869	516	2.6	1195	0	0.0	30	112	3.1	1.12	3.92
1 RAW WATER PUMPING	25.0	1571	1885	1231	7.0	1609	0	0.0	60	238	2.6	0.95	3.33
1 RAW WATER PUMPING	50.0	2784	3341	2347	13.0	2498	0	0.0	108	423	2.3	0.85	2.96
2 RAPID MIX	1.0	10	12	32	0.2	470	0	0.0	6	7	1.9	0.70	2.45
2 RAPID MIX	5.0	22	26	157	0.5	468	0	0.0	10	12	0.7	0.24	0.84
2 RAPID MIX	10.0	37	44	315	0.8	469	0	0.0	15	19	0.5	0.19	0.66
2 RAPID MIX	25.0	80	96	787	1.8	499	0	0.0	30	39	0.4	0.16	0.55
2 RAPID MIX	50.0	150	180	1574	3.3	617	0	0.0	57	74	0.4	0.15	0.52
3 ALUM FEED SYSTEM	1.0	26	31	9	0.2	290	0	61.3	8	11	3.0	1.10	3.85
3 ALUM FEED SYSTEM	5.0	51	61	14	0.2	329	0	306.6	27	33	1.8	0.66	2.31
3 ALUM FEED SYSTEM	10.0	77	92	19	0.2	378	0	608.8	50	59	1.6	0.59	2.07
3 ALUM FEED SYSTEM	25.0	132	153	32	0.2	548	0	1524.2	121	136	1.5	0.54	1.90
3 ALUM FEED SYSTEM	50.0	157	188	50	0.3	884	0	3044.1	239	257	1.4	0.51	1.80
4 POLYMER FEED SYSTEMS	1.0	22	26	23	0.2	198	0	0.2	4	6	1.6	0.60	2.10
4 POLYMER FEED SYSTEMS	5.0	23	28	23	0.2	198	0	0.8	6	9	0.5	0.18	0.63
4 POLYMER FEED SYSTEMS	10.0	26	31	23	0.3	199	0	1.5	9	12	0.3	0.12	0.42
4 POLYMER FEED SYSTEMS	25.0	33	40	23	0.3	201	0	3.8	18	22	0.2	0.09	0.31
4 POLYMER FEED SYSTEMS	50.0	67	80	46	0.6	403	0	7.6	36	44	0.2	0.09	0.31
5 FLOCCULATION	1.0	41	49	9	0.4	105	0	0.0	2	7	1.9	0.70	2.45
5 FLOCCULATION	5.0	111	133	47	1.0	161	0	0.0	4	17	0.9	0.34	1.19
5 FLOCCULATION	10.0	187	224	94	1.8	218	0	0.0	7	28	0.8	0.28	0.98
5 FLOCCULATION	25.0	342	410	234	3.5	312	0	0.0	14	53	0.6	0.21	0.74
5 FLOCCULATION	50.0	417	500	468	5.3	349	0	0.0	23	70	0.4	0.14	0.49
6 CIRCULAR CLARIFIER	1.0	152	182	10	0.5	274	0	0.0	3	20	5.5	2.00	7.00
6 CIRCULAR CLARIFIER	5.0	319	383	11	1.2	527	0	0.0	7	43	2.4	0.86	3.01
6 CIRCULAR CLARIFIER	10.0	521	625	14	2.0	802	0	0.0	10	69	1.9	0.69	2.42
6 CIRCULAR CLARIFIER	25.0	1240	1488	29	4.7	1851	0	0.0	24	164	1.8	0.66	2.30
6 CIRCULAR CLARIFIER	50.0	2172	2606	39	8.2	2844	0	0.0	38	284	1.6	0.57	1.99
7 CHLORINE FEED SYSTEMS	1.0	15	18	4	1.8	410	0	15.3	9	11	3.0	1.10	3.85
7 CHLORINE FEED SYSTEMS	5.0	35	42	11	2.4	749	0	76.3	27	31	1.7	0.62	2.17
7 CHLORINE FEED SYSTEMS	10.0	57	68	18	3.1	1129	0	152.4	48	54	1.5	0.54	1.89
7 CHLORINE FEED SYSTEMS	25.0	106	127	33	4.6	2020	0	381.1	110	122	1.3	0.49	1.71
7 CHLORINE FEED SYSTEMS	50.0	148	178	43	5.4	2907	0	761.9	203	220	1.2	0.44	1.54

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS* THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
8 CHEMICAL SLUDGE PUMPING-DILUTE	1.0	24	29	0	1.4	45	0	0.0	2	5	1.4	0.50	1.75
8 CHEMICAL SLUDGE PUMPING-DILUTE	5.0	49	59	2	2.8	98	0	0.0	4	10	0.5	0.20	0.70
8 CHEMICAL SLUDGE PUMPING-DILUTE	10.0	50	60	4	3.7	136	0	0.0	5	11	0.3	0.11	0.39
8 CHEMICAL SLUDGE PUMPING-DILUTE	25.0	63	76	9	3.7	154	0	0.0	5	12	0.1	0.05	0.17
8 CHEMICAL SLUDGE PUMPING-DILUTE	50.0	84	101	18	4.5	200	0	0.0	7	17	0.1	0.03	0.12
9 GRAVITY THICKENER	1.0	65	78	3	0.1	298	0	0.0	3	10	2.7	1.00	3.50
9 GRAVITY THICKENER	5.0	65	78	3	0.1	298	0	0.0	3	10	0.5	0.20	0.70
9 GRAVITY THICKENER	10.0	65	78	3	0.1	298	0	0.0	3	10	0.3	0.10	0.35
9 GRAVITY THICKENER	25.0	73	88	3	0.1	305	0	0.0	3	11	0.1	0.04	0.15
9 GRAVITY THICKENER	50.0	87	104	3	0.2	316	0	0.0	3	13	0.1	0.03	0.09
10 CHEMICAL SLUDGE PUMPING-DILUTE	1.0	14	17	0	1.2	35	0	0.0	2	4	1.1	0.40	1.40
10 CHEMICAL SLUDGE PUMPING-DILUTE	5.0	26	31	1	2.0	67	0	0.0	3	6	0.3	0.12	0.42
10 CHEMICAL SLUDGE PUMPING-DILUTE	10.0	37	44	2	2.8	98	0	0.0	4	8	0.2	0.08	0.28
10 CHEMICAL SLUDGE PUMPING-DILUTE	25.0	51	61	4	3.8	142	0	0.0	5	11	0.1	0.04	0.15
10 CHEMICAL SLUDGE PUMPING-DILUTE	50.0	52	62	9	3.7	154	0	0.0	5	11	0.1	0.02	0.08
11 DECANTER CENTRIFUGE	1.0	150	180	38	1.5	729	0	0.0	10	27	7.4	2.70	9.45
11 DECANTER CENTRIFUGE	5.0	156	187	45	1.7	772	0	0.0	11	29	1.6	0.58	2.03
11 DECANTER CENTRIFUGE	10.0	179	215	71	2.6	936	0	0.0	14	34	0.9	0.34	1.19
11 DECANTER CENTRIFUGE	25.0	241	289	146	5.2	1383	0	0.0	23	50	0.5	0.20	0.70
11 DECANTER CENTRIFUGE	50.0	313	376	252	8.3	1906	0	0.0	35	70	0.4	0.14	0.49
12 SLUDGE HAULING	1.0	0	0	0	0.5	64	0	0.0	1	1	0.3	0.10	0.35
12 SLUDGE HAULING	5.0	0	0	0	1.0	214	0	0.0	3	3	0.2	0.06	0.21
12 SLUDGE HAULING	10.0	0	0	0	1.7	404	0	0.0	6	6	0.2	0.06	0.21
12 SLUDGE HAULING	25.0	0	0	0	3.7	988	0	0.0	14	14	0.2	0.06	0.20
12 SLUDGE HAULING	50.0	0	0	0	7.2	2007	0	0.0	27	27	0.1	0.05	0.19

TOTAL COST FOR COMPONENTS 1 THRU 12: CLARIFICATION AND CHLORINATION

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS* THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
CLARIFICATION AND CHLORINATION	1.0	762	914	198	8.6	3930	0	76.8	63	139	38.1	13.90	48.65
CLARIFICATION AND CHLORINATION	5.0	1452	1743	583	14.7	4968	0	383.7	125	270	14.8	5.40	18.90
CLARIFICATION AND CHLORINATION	10.0	2248	2697	1079	21.7	6262	0	762.7	201	422	11.6	4.22	14.77
CLARIFICATION AND CHLORINATION	25.0	4516	5422	2531	38.6	10012	0	1909.1	427	872	9.6	3.49	12.21
CLARIFICATION AND CHLORINATION	50.0	7390	8870	4849	59.9	15085	0	3813.6	781	1510	8.3	3.02	10.57

THE FOLLOWING 5 PROCESSES ARE COST COMPONENTS OF RAPID SAND FILTRATION

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS* THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
13 GRAVITY FILTRATION STRUCTURE	1.0	223	268	19	2.1	1966	0	0.0	22	47	12.9	4.70	16.45
13 GRAVITY FILTRATION STRUCTURE	5.0	758	910	68	8.6	2769	0	0.0	38	124	6.8	2.48	8.68
13 GRAVITY FILTRATION STRUCTURE	10.0	1321	1585	122	15.6	3903	0	0.0	58	208	5.7	2.08	7.28
13 GRAVITY FILTRATION STRUCTURE	25.0	2479	2975	247	31.5	8047	0	0.0	119	400	4.4	1.60	5.60
13 GRAVITY FILTRATION STRUCTURE	50.0	3590	4308	370	49.7	16296	0	0.0	224	631	3.5	1.26	4.42

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL	ANNUAL	COST	FACTORS*
										THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
14 FILTRA-HYDRAULIC SURFACE WASH	1.0	13	16	5	0.0	58	0	0.0	1	3	0.8	0.30	1.05
14 FILTRA-HYDRAULIC SURFACE WASH	5.0	64	77	26	0.0	289	0	0.0	4	11	0.6	0.22	0.77
14 FILTRA-HYDRAULIC SURFACE WASH	10.0	85	102	49	0.0	306	0	0.0	5	15	0.4	0.15	0.52
14 FILTRA-HYDRAULIC SURFACE WASH	25.0	167	200	121	0.1	373	0	0.0	7	26	0.3	0.10	0.36
14 FILTRA-HYDRAULIC SURFACE WASH	50.0	298	358	246	0.1	473	0	0.0	12	46	0.3	0.09	0.32
15 FILTRA-BACKWASH PUMPING SYSTEM	1.0	116	139	8	0.0	6	0	0.0	0	13	3.6	1.30	4.55
15 FILTRA-BACKWASH PUMPING SYSTEM	5.0	580	696	42	0.2	29	0	0.0	2	68	3.7	1.36	4.76
15 FILTRA-BACKWASH PUMPING SYSTEM	10.0	814	977	83	0.3	34	0	0.0	3	95	2.6	0.95	3.33
15 FILTRA-BACKWASH PUMPING SYSTEM	25.0	1225	1470	206	0.6	52	0	0.0	7	146	1.6	0.58	2.04
15 FILTRA-BACKWASH PUMPING SYSTEM	50.0	2405	2886	415	1.1	71	0	0.0	14	286	1.6	0.57	2.00
16 MEDIA-RAPID SAND FILTRATION	1.0	8	10	0	0.0	0	0	0.0	0	1	0.3	0.10	0.35
16 MEDIA-RAPID SAND FILTRATION	5.0	18	22	0	0.0	0	0	0.0	0	2	0.1	0.04	0.14
16 MEDIA-RAPID SAND FILTRATION	10.0	30	36	0	0.0	0	0	0.0	0	3	0.1	0.03	0.11
16 MEDIA-RAPID SAND FILTRATION	25.0	65	78	0	0.0	0	0	0.0	0	7	0.1	0.03	0.10
16 MEDIA-RAPID SAND FILTRATION	50.0	121	145	0	0.0	0	0	0.0	0	14	0.1	0.03	0.10
17 SUPPLY PUMPING	1.0	30	36	45	0.3	520	0	0.0	7	10	2.7	1.00	3.50
17 SUPPLY PUMPING	5.0	47	56	226	0.9	623	0	0.0	14	19	1.0	0.38	1.33
17 SUPPLY PUMPING	10.0	69	83	451	1.6	747	0	0.0	23	31	0.8	0.31	1.09
17 SUPPLY PUMPING	25.0	132	158	1128	3.7	1096	0	0.0	49	64	0.7	0.26	0.90
17 SUPPLY PUMPING	50.0	234	281	2254	7.6	1618	0	0.0	91	118	0.6	0.24	0.83
TOTAL COST FOR COMPONENTS 13 THRU 17: RAPID SAND FILTRATION													
RAPID SAND FILTRATION	1.0	446	537	77	2.5	2550	0	0.0	30	74	20.3	7.40	25.90
RAPID SAND FILTRATION	5.0	1685	2023	362	9.6	3710	0	0.0	58	224	12.3	4.48	15.68
RAPID SAND FILTRATION	10.0	2665	3198	705	17.4	4990	0	0.0	89	352	9.6	3.52	12.32
RAPID SAND FILTRATION	25.0	4675	5611	1702	35.9	9568	0	0.0	182	643	7.0	2.57	9.00
RAPID SAND FILTRATION	50.0	7643	9172	3285	58.5	18458	0	0.0	341	1095	6.0	2.19	7.67
THE FOLLOWING 7 PROCESSES ARE COST COMPONENTS OF MIXED MEDIA FILTRATION													
18 GRAVITY FILTRATION STRUCTURE	1.0	136	163	11	1.1	1856	0	0.0	20	35	9.6	3.50	12.25
18 GRAVITY FILTRATION STRUCTURE	5.0	364	437	32	3.8	2157	0	0.0	26	67	3.7	1.34	4.69
18 GRAVITY FILTRATION STRUCTURE	10.0	631	757	56	7.0	2558	0	0.0	34	105	2.9	1.05	3.67
18 GRAVITY FILTRATION STRUCTURE	25.0	1321	1585	122	15.6	3903	0	0.0	58	208	2.3	0.83	2.91
18 GRAVITY FILTRATION STRUCTURE	50.0	2165	2598	211	26.9	6560	0	0.0	99	344	1.9	0.69	2.41

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS*			
										THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
19 FILTRA-HYDRAULIC SURFACE WASH	1.0	11	13	2	0.0	54	0	0.0	1	2	0.5	0.20	0.70
19 FILTRA-HYDRAULIC SURFACE WASH	5.0	25	30	10	0.0	115	0	0.0	1	4	0.2	0.08	0.28
19 FILTRA-HYDRAULIC SURFACE WASH	10.0	42	50	20	0.0	178	0	0.0	2	7	0.2	0.07	0.25
19 FILTRA-HYDRAULIC SURFACE WASH	25.0	77	92	49	0.0	248	0	0.0	4	13	0.1	0.05	0.18
19 FILTRA-HYDRAULIC SURFACE WASH	50.0	135	162	97	0.1	311	0	0.0	6	21	0.1	0.04	0.15
20 FILTRA-BACKWASH PUMPING SYSTEM	1.0	71	85	3	0.0	5	0	0.0	0	8	2.2	0.80	2.80
20 FILTRA-BACKWASH PUMPING SYSTEM	5.0	232	278	17	0.1	12	0	0.0	1	27	1.5	0.54	1.89
20 FILTRA-BACKWASH PUMPING SYSTEM	10.0	404	485	33	0.1	19	0	0.0	1	47	1.3	0.47	1.65
20 FILTRA-BACKWASH PUMPING SYSTEM	25.0	707	848	83	0.2	29	0	0.0	3	83	0.9	0.33	1.16
20 FILTRA-BACKWASH PUMPING SYSTEM	50.0	1009	1211	166	0.4	43	0	0.0	6	120	0.7	0.24	0.84
21 MEDIA-MIXED MEDIA FILTRATION	1.0	8	10	0	0.0	0	0	0.0	0	1	0.3	0.10	0.35
21 MEDIA-MIXED MEDIA FILTRATION	5.0	24	29	0	0.0	0	0	0.0	0	3	0.2	0.06	0.21
21 MEDIA-MIXED MEDIA FILTRATION	10.0	44	53	0	0.0	0	0	0.0	0	5	0.1	0.05	0.18
21 MEDIA-MIXED MEDIA FILTRATION	25.0	98	118	0	0.0	0	0	0.0	0	11	0.1	0.04	0.15
21 MEDIA-MIXED MEDIA FILTRATION	50.0	178	214	0	0.0	0	0	0.0	0	20	0.1	0.04	0.14
22 SUPPLY PUMPING	1.0	30	36	45	0.3	520	0	0.0	7	10	2.7	1.00	3.50
22 SUPPLY PUMPING	5.0	47	56	226	0.9	623	0	0.0	14	19	1.0	0.38	1.33
22 SUPPLY PUMPING	10.0	69	83	451	1.6	747	0	0.0	23	31	0.8	0.31	1.09
22 SUPPLY PUMPING	25.0	132	158	1128	3.7	1096	0	0.0	49	64	0.7	0.26	0.90
22 SUPPLY PUMPING	50.0	234	281	2254	7.6	1618	0	0.0	91	118	0.6	0.24	0.83
23 POLYMER FEED SYSTEMS	1.0	22	26	23	0.2	198	0	0.2	4	6	1.6	0.60	2.10
23 POLYMER FEED SYSTEMS	5.0	23	28	23	0.2	198	0	0.8	6	9	0.5	0.18	0.63
23 POLYMER FEED SYSTEMS	10.0	26	31	23	0.3	199	0	1.5	9	12	0.3	0.12	0.42
23 POLYMER FEED SYSTEMS	25.0	33	40	23	0.3	201	0	3.8	18	22	0.2	0.09	0.31
23 POLYMER FEED SYSTEMS	50.0	67	80	46	0.6	403	0	7.6	36	44	0.2	0.09	0.31
24 ALUM FEED SYSTEM	1.0	22	26	9	0.2	284	0	15.3	4	6	1.6	0.60	2.10
24 ALUM FEED SYSTEM	5.0	31	37	10	0.2	293	0	76.2	9	12	0.7	0.24	0.84
24 ALUM FEED SYSTEM	10.0	41	49	11	0.2	304	0	152.4	15	20	0.5	0.20	0.70
24 ALUM FEED SYSTEM	25.0	69	83	15	0.2	341	0	381.1	33	41	0.4	0.16	0.57
24 ALUM FEED SYSTEM	50.0	106	127	21	0.2	405	0	762.1	62	74	0.4	0.15	0.52
TOTAL COST FOR COMPONENTS 18 THRU 24: MIXED MEDIA FILTRATION													
MIXED MEDIA FILTRATION	1.0	342	408	93	1.9	2917	0	15.5	36	68	18.6	6.80	23.80
MIXED MEDIA FILTRATION	5.0	854	1026	318	5.2	3398	0	77.0	57	141	7.7	2.82	9.87
MIXED MEDIA FILTRATION	10.0	1442	1730	594	9.1	4005	0	153.9	84	227	6.2	2.27	7.95
MIXED MEDIA FILTRATION	25.0	2799	3359	1420	20.1	5818	0	384.9	165	442	4.8	1.77	6.19
MIXED MEDIA FILTRATION	50.0	4475	5372	2795	35.8	9340	0	769.7	300	741	4.1	1.48	5.19

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS** THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME

THE FOLLOWING 3 PROCESSES ARE COST COMPONENTS OF ACTIVATED CARBON ADSORPTION

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS** THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
25 GRANULAR ACT CARBON CONTACTORS	1.0	197	236	32	1.4	1851	0	0.0	21	43	11.8	4.30	15.05
25 GRANULAR ACT CARBON CONTACTORS	5.0	503	604	57	4.7	2194	0	0.0	28	85	4.7	1.70	5.95
25 GRANULAR ACT CARBON CONTACTORS	10.0	859	1031	86	8.6	2640	0	0.0	38	135	3.7	1.35	4.73
25 GRANULAR ACT CARBON CONTACTORS	25.0	1761	2113	164	18.9	4081	0	0.0	65	264	2.9	1.06	3.70
25 GRANULAR ACT CARBON CONTACTORS	50.0	2808	3370	265	32.0	6781	0	0.0	108	426	2.3	0.85	2.98
26 GRANULAR ACTIVATED CARBON	1.0	13	16	0	0.0	0	0	0.0	0	2	0.5	0.20	0.70
26 GRANULAR ACTIVATED CARBON	5.0	61	73	0	0.0	0	0	0.0	0	7	0.4	0.14	0.49
26 GRANULAR ACTIVATED CARBON	10.0	121	145	0	0.0	0	0	0.0	0	14	0.4	0.14	0.49
26 GRANULAR ACTIVATED CARBON	25.0	300	360	0	0.0	0	0	0.0	0	34	0.4	0.14	0.48
26 GRANULAR ACTIVATED CARBON	50.0	595	714	0	0.0	0	0	0.0	0	67	0.4	0.13	0.47
27 GRAN ACT CARBON REGENERATION	1.0	581	697	161	1.2	188	458	1.2	11	77	21.1	7.70	26.95
27 GRAN ACT CARBON REGENERATION	5.0	581	697	191	2.1	509	1978	6.1	27	93	5.1	1.86	6.51
27 GRAN ACT CARBON REGENERATION	10.0	701	841	222	3.0	890	3791	12.1	46	125	3.4	1.25	4.38
27 GRAN ACT CARBON REGENERATION	25.0	1026	1231	273	4.4	1798	8145	30.5	95	211	2.3	0.84	2.95
27 GRAN ACT CARBON REGENERATION	50.0	1473	1768	321	5.9	3327	14914	60.9	173	340	1.9	0.68	2.38

TOTAL COST FOR COMPONENTS 25 THRU 27: ACTIVATED CARBON ADSORPTION

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS** THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
ACTIVATED CARBON ADSORPTION	1.0	908	1090	193	2.6	2039	458	1.2	32	122	33.4	12.20	42.70
ACTIVATED CARBON ADSORPTION	5.0	1316	1578	248	6.8	2703	1978	6.1	55	185	10.1	3.70	12.95
ACTIVATED CARBON ADSORPTION	10.0	1932	2318	308	11.6	3530	3791	12.1	84	274	7.5	2.74	9.59
ACTIVATED CARBON ADSORPTION	25.0	3549	4258	437	23.2	5879	8145	30.5	160	509	5.6	2.04	7.13
ACTIVATED CARBON ADSORPTION	50.0	5606	6729	586	37.8	10108	14914	60.9	281	833	4.6	1.67	5.83

***** TREATMENT SYSTEM COST SUMMARIES INCLUDING YARD PIPING AT 15 PERCENT OF CONSTRUCTION COST *****

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS** THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
CONVENTIONAL WATER TREATMENT	1.0	1208	1451	275	11.1	6480	0	76.8	93	213	58.4	21.30	74.55
CONVENTIONAL WATER TREATMENT	5.0	3137	3766	945	24.3	8678	0	383.7	183	494	27.1	9.88	34.58
CONVENTIONAL WATER TREATMENT	10.0	4913	5895	1784	39.2	11252	0	762.7	290	774	21.2	7.74	27.09
CONVENTIONAL WATER TREATMENT	25.0	9191	11033	4233	74.5	19580	0	1909.1	609	1515	16.6	6.06	21.21
CONVENTIONAL WATER TREATMENT	50.0	15033	18042	8134	118.5	33543	0	3813.6	1122	2605	14.3	5.21	18.24
UPGRADED WATER TREATMENT	1.0	2012	2412	484	13.1	8886	458	93.5	131	329	90.1	32.90	115.15
UPGRADED WATER TREATMENT	5.0	3622	4347	1149	26.6	11069	1978	466.7	237	596	32.7	11.92	41.72
UPGRADED WATER TREATMENT	10.0	5622	6745	1981	42.5	13797	3791	928.8	369	923	25.3	9.23	32.31
UPGRADED WATER TREATMENT	25.0	10864	13039	4388	81.9	21709	8145	2324.4	752	1823	20.0	7.29	25.52
UPGRADED WATER TREATMENT	50.0	17471	20971	8230	133.6	34533	14914	4644.2	1362	3084	16.9	6.17	21.59

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        DESIGN CRITERIA AND UNIT PROCESS SIZES
PROCESS OR COMPONENT                       DESIGN FLOW,MGD
                                                 AVERAGE:      1.0       5.0      10.0      25.0      50.0
                                                 PEAK:         1.0       5.0      10.0      25.0      50.0

 1 RAW WATER PUMPING, FIRM CAPACITY, MGD                       1.0       5.0      10.0      25.0      50.0
   INCLUDES SCREENING & ONE STANDBY PUMP EQUAL TO LARGEST UNIT

 2 RAPID MIX BASIN, VOLUME, CU FT                             93.0     464.0     928.0    2320.0    4640.0
   NUMBER OF UNITS                                               1         1         1         1         1
   1 MIN DETENTION TIME AT AVERAGE FLOW

 3 ALUM FEED SYSTEM-DRY ALUM, CAPACITY, LBS/HR                21.0     104.0     208.0     521.0    1040.0
   ALUM COAGULATION, CAPACITY=60 MG/L, AVG=40 MG/L

 4 POLYMER FEED SYSTEMS, FEED CAPACITY/UNIT, LBS/DAY           8.3      42.0      83.0     208.0     208.0
   NUMBER OF UNITS                                               1         1         1         1         2
   COAGULANT AID, CAPACITY=1 MG/L, AVG=0.1 MG/L DOSE

 5 FLOCCULATION, TOTAL BASIN VOLUME, CU FT                  2780.0   13900.0   27800.0   69500.0  139000.0
   HORIZONTAL PADDLE, G=80, DETENTION TIME=30 MIN AT AVG FLOW

 6 CIRCULAR CLARIFIER, SURFACE AREA/UNIT, SQ FT              526.0    2630.0    5260.0    6580.0   13200.0
   NUMBER OF UNITS                                               2         2         2         4         4
   OVERFLOW RATE=950 GAL/DAY/SQ FT

 7 CHLORINE FEED SYSTEMS, FEED CAPACITY, LB/DAY               84.0     418.0     835.0    2088.0    4175.0
   CAPACITY=10 MG/L DOSE

 8 CHEMICAL SLUDGE PUMPING, FIRM PUMPING CAPACITY, GPM        12.0      56.0     112.0     278.0     555.0
   CAPACITY=40 MG/L AT PEAK FLOW AND 0.5% SOLIDS

 9 GRAVITY THICKENER, SURFACE AREA/UNIT, SQ FT                78.0      78.0      78.0     200.0     400.0
   NUMBER OF UNITS                                               1         1         1         1         1
   ALUM SLUDGE,OVERFLOW RATE=1000 GPD/SQ FT WITH 0.5% SOLIDS IN

10 CHEMICAL SLUDGE PUMPING,  FIRM PUMPING CAPACITY, GPM         3.0      14.0      28.0      69.0     139.0
   THICKENED ALUM SLUDGE, 1% SOLIDS

11 DECANTER CENTRUFUGE, CENTRIFUGE CAPACITY, GPM              10.0      13.0      25.0      63.0     125.0
   NUMBER OF UNITS                                               1         1         1         1         1
   ALUM SLUDGE AT 1% SOLIDS INFLUENT CONCENTRATION

12 SLUDGE HAULING, ANNUAL VOLUME, CU YD                      361.0    1810.0    3610.0    9030.0   18100.0
   ALUM SLUDGE, CONCENTRATED TO 20% SOLIDS

13 GRAVITY FILTRATION STRUCTURE, TOTAL FILTER AREA, SQ FT    347.0    1740.0    3470.0    8680.0   17400.0
   RAPID SAND FILTER, FILTRATION RATE=2 GPM/SQ FT, WATER TREAT

14 FILTRA-HYDRAULIC SURFACE WASH, INDIVIDUAL FILTER AREA, SQ FT 174.0  174.0     347.0     723.0    1240.0
   NUMBER OF UNITS                                               2        10        10        12        14
   RAPID SAND FILTER, FILTRATION RATE=2 GPM/SQ FT, WATER TREAT

15 FILTRA-BACKWASH PUMPING SYSTEM, FIRM PUMPING CAPACITY, GPM 3130.0   3130.0    6250.0   13000.0   22300.0
   NUMBER OF UNITS                                               2        10        10        12        14
   RAPID SAND FILTER, BACKWASH CAPACITY = 18 GPM/SQ FT
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           DESIGN CRITERIA AND UNIT PROCESS SIZES

PROCESS OR COMPONENT                            DESIGN FLOW,MGD
                                                      AVERAGE:       1.0       5.0      10.0      25.0      50.0
                                                         PEAK:       1.0       5.0      10.0      25.0      50.0


 16 MEDIA-RAPID SAND FILTRATION, TOTAL FILTER AREA, SQ FT          347.0    1740.0    3470.0    8680.0   17400.0
    RAPID SAND FILTER, WATER TREAT, FILTRATION RATE=2 GPM/SQ FT

 17 SUPPLY PUMPING, PUMPING RATE, MGD                                1.0       5.0      10.0      25.0      50.0
    GRAVITY FILTER OR AWT UPFLOW CARBON CONTACTOR SUPPLY

 18 GRAVITY FILTRATION STRUCTURE, TOTAL FILTER AREA, SQ FT         139.0     694.0    1390.0    3470.0    6940.0
    MIXED MEDIA FILTER, FILTRATION RATE=5 GPM/SQ FT, WATER & AWT

 19 FILTRA-HYDRAULIC SURFACE WASH, INDIVIDUAL FILTER AREA, SQ FT    69.0     174.0     231.0     434.0     694.0
    NUMBER OF UNITS                                                    2         4         6         8        10
    MIXED MEDIA FILTER, FILTRATION RATE=5 GPM/SQ FT, WATER & AWT

 20 FILTRA-BACKWASH PUMPING SYSTEM, FIRM PUMPING CAPACITY, GPM     1240.0    3130.0    4160.0    7810.0   12500.0
    NUMBER OF UNITS                                                    2         4         6         8        10
    MIXED MEDIA FILTER,WATER&AWT, BACKWASH CAPACITY=18 GPM/SQ FT

 21 MEDIA-MIXED MEDIA FILTRATION, TOTAL FILTER AREA, SQ FT         139.0     694.0    1390.0    3470.0    6940.0
    MIXED MEDIA FILTER, WATER & AWT, FILTRATION RATE=5 GPM/SQ FT

 22 SUPPLY PUMPING,PUMPING RATE, MGD                                 1.0       5.0      10.0      25.0      50.0
    GRAVITY FILTER OR AWT UPFLOW CARBON CONTACTOR SUPPLY

 23 POLYMER FEED SYSTEMS, FEED CAPACITY/UNIT, LBS/DAY                8.3      42.0      83.0     208.0     208.0
    NUMBER OF UNITS                                                    1         1         1         1         2
    FILTRATION AND COAGULANT AID,1 MG/L CAPACITY,0.1 MG/L AVG

 24 ALUM FEED SYSTEM-DRY ALUM, CAPACITY, LBS/HR                      7.0      34.8      69.6     174.0     348.0
    MIXED MEDIA FILTER AID, 20 MG/L CAPACITY, 10 MG/L AVG

 25 GRANULAR ACT CARBON CONTACTORS, TOTAL CONTACTOR AREA,SQ FT     140.0     700.0    1400.0    3500.0    7000.0
    GRAVITY DOWNFLOW, CONTACT TIME 7.5 MIN, RATE 5 GPM/SQ FT

 26 GRANULAR ACTIVATED CARBON, TOTAL WEIGHT OF CARBON, LBS       21000.0  105000.0  210000.0  525000.0 1050000.0
    CONTACT TIME=7.5 MIN, CARBON WEIGHT=30 LB/ CU FT

 27 GRANULAR CARBON REGENERATION, HEARTH AREA, SQ FT                28.0      28.0      56.0     139.0     278.0
    40% DOWNTIME,40 LB/SQ FT/DAY; REMOVAL=0.5 LB COD/LB CARBON
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COST INFORMATION:

 COSTS PRESENTED AS DOLLARS ARE CURRENT AS OF JANUARY 1977

 CAPITAL COST FACTORS:  INTEREST RATE(%)    =7
                        NUMBER OF YEARS     =20
                        ENGINEERING(%)      =10    (PER CENT OF CONSTRUCTION COST)
                        LEGAL,FISCAL(%)     =3     (PER CENT OF CONSTRUCTION COST)
                        INT DURING CONST(%)=7      (PER CENT OF CONSTRUCTION COST)
                        YARD PIPING FACTOR =15     (PER CENT OF CONSTRUCTION COST)

 PER CAPITA COSTS:      GAL/PERSON/DAY      =100
                        PEOPLE/HOME         =3.5

 UNIT COST FACTORS:     ELECTRICITY,$/KWH   =0.03
                        LABOR,$/HR          =10
                        FUEL,$/MIL BTU      =3

 CHEMICAL COSTS:        LIME,$/TON          =52
                        ALUM,$/TON          =75
                        CHLORINE,$/TON      =220
                        POLYMER,$/LB        =2

 CONSTN COST INDEXES:   EXCAVATION          =220.6  (ENR SKILLED LABOR)
                        MANUFACTURED EQUIP =195.7  (BLS #114)
                        CONCRETE            =193.1  (BLS #132)
                        STEEL               =221.3  (BLS #101.3)
                        LABOR               =220.6  (ENR SKILLED LABOR)
                        PIPES & VALVES      =209.4  (BLS #114.901)
                        HOUSING             =30     (ACTUAL BLDG COST,$/SQ FT)
                        WHOLESALE PRICE     =188.0  (BLS ALL COMMODITIES)

 EPA CONSTN INDEXES:    SCCT(5 MGD PLANT)   =121    (NATIONAL INDEX VALUE)
                        LCAT(50 MGD PLANT) =132    (NATIONAL INDEX VALUE)
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COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL	ANNUAL	COST	FACTORS*
										THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
THE FOLLOWING 12 PROCESSES ARE COST COMPONENTS OF CLARIFICATION AND CHLORINATION													
1 RAW WATER PUMPING	1.0	165	198	82	0.6	1017	0	0.0	13	32	8.8	3.20	11.20
1 RAW WATER PUMPING	5.0	491	589	331	1.7	1112	0	0.0	23	79	4.3	1.58	5.53
1 RAW WATER PUMPING	10.0	874	1049	637	3.3	1255	0	0.0	35	134	3.7	1.34	4.69
1 RAW WATER PUMPING	25.0	1798	2158	1435	8.3	1751	0	0.0	69	273	3.0	1.09	3.82
1 RAW WATER PUMPING	50.0	3189	3827	2717	13.5	2839	0	0.0	123	484	2.7	0.97	3.39
2 RAPID MIX	1.0	22	26	39	0.3	470	0	0.0	6	8	2.2	0.80	2.80
2 RAPID MIX	5.0	51	61	197	0.6	468	0	0.0	11	17	0.9	0.34	1.19
2 RAPID MIX	10.0	88	106	394	1.0	472	0	0.0	18	28	0.8	0.28	0.98
2 RAPID MIX	25.0	185	222	926	2.0	514	0	0.0	35	56	0.6	0.22	0.78
2 RAPID MIX	50.0	348	418	1852	3.9	675	0	0.0	66	105	0.6	0.21	0.74
3 ALUM FEED SYSTEM	1.0	36	43	10	0.2	293	0	76.7	9	13	3.6	1.30	4.55
3 ALUM FEED SYSTEM	5.0	89	107	15	0.2	341	0	383.2	33	43	2.4	0.86	3.01
3 ALUM FEED SYSTEM	10.0	132	158	21	0.2	405	0	762.1	62	77	2.1	0.77	2.70
3 ALUM FEED SYSTEM	25.0	151	181	36	0.3	602	0	1791.4	142	159	1.7	0.64	2.23
3 ALUM FEED SYSTEM	50.0	38	46	55	0.3	1016	0	3582.8	281	285	1.6	0.57	2.00
4 POLYMER FEED SYSTEMS	1.0	44	53	23	0.2	198	0	0.4	4	9	2.5	0.90	3.15
4 POLYMER FEED SYSTEMS	5.0	47	56	23	0.2	199	0	1.9	11	16	0.9	0.32	1.12
4 POLYMER FEED SYSTEMS	10.0	54	65	23	0.3	200	0	3.8	18	24	0.7	0.24	0.84
4 POLYMER FEED SYSTEMS	25.0	87	104	46	0.5	400	0	6.8	33	43	0.5	0.17	0.60
4 POLYMER FEED SYSTEMS	50.0	126	151	69	0.8	602	0	11.9	56	70	0.4	0.14	0.49
5 FLOCCULATION	1.0	68	82	23	0.7	127	0	0.0	3	11	3.0	1.10	3.85
5 FLOCCULATION	5.0	178	214	88	1.7	211	0	0.0	6	26	1.4	0.52	1.82
5 FLOCCULATION	10.0	290	348	175	2.9	284	0	0.0	11	44	1.2	0.44	1.54
5 FLOCCULATION	25.0	415	498	413	5.0	343	0	0.0	21	68	0.7	0.27	0.95
5 FLOCCULATION	50.0	0	0	826	6.6	673	0	0.0	38	38	0.2	0.08	0.27
6 CIRCULAR CLARIFIER	1.0	244	293	10	0.5	291	0	0.0	4	32	8.8	3.20	11.20
6 CIRCULAR CLARIFIER	5.0	555	666	12	1.4	600	0	0.0	8	71	3.9	1.42	4.97
6 CIRCULAR CLARIFIER	10.0	929	1115	15	2.4	925	0	0.0	12	117	3.2	1.17	4.10
6 CIRCULAR CLARIFIER	25.0	1057	1268	16	2.7	1026	0	0.0	13	133	1.5	0.53	1.86
6 CIRCULAR CLARIFIER	50.0	1858	2230	21	4.6	1560	0	0.0	21	231	1.3	0.46	1.62
7 CHLORINE FEED SYSTEMS	1.0	16	19	4	1.8	432	0	19.2	10	12	3.3	1.20	4.20
7 CHLORINE FEED SYSTEMS	5.0	41	49	13	2.6	849	0	95.4	32	37	2.0	0.74	2.59
7 CHLORINE FEED SYSTEMS	10.0	67	80	21	3.4	1303	0	190.5	59	67	1.8	0.67	2.34
7 CHLORINE FEED SYSTEMS	25.0	116	139	36	4.8	2221	0	448.2	127	140	1.5	0.56	1.96
7 CHLORINE FEED SYSTEMS	50.0	156	187	43	5.5	3122	0	896.4	235	253	1.4	0.51	1.77

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL THOU $	COST CTS/ K GAL	FACTORS* $ PER CAPITA	$ PER HOME
8 CHEMICAL SLUDGE PUMPING-DILUTE	1.0	26	31	0	1.5	49	0	0.0	2	5	1.4	0.50	1.75
8 CHEMICAL SLUDGE PUMPING-DILUTE	5.0	51	61	2	3.2	111	0	0.0	4	10	0.5	0.20	0.70
8 CHEMICAL SLUDGE PUMPING-DILUTE	10.0	52	62	4	3.8	143	0	0.0	5	11	0.3	0.11	0.39
8 CHEMICAL SLUDGE PUMPING-DILUTE	25.0	67	80	10	3.8	162	0	0.0	6	14	0.2	0.06	0.20
8 CHEMICAL SLUDGE PUMPING-DILUTE	50.0	91	109	21	4.7	216	0	0.0	8	18	0.1	0.04	0.13
9 GRAVITY THICKENER	1.0	65	78	3	0.1	298	0	0.0	3	10	2.7	1.00	3.50
9 GRAVITY THICKENER	5.0	65	78	3	0.1	298	0	0.0	3	10	0.5	0.20	0.70
9 GRAVITY THICKENER	10.0	66	79	3	0.1	300	0	0.0	3	10	0.3	0.10	0.35
9 GRAVITY THICKENER	25.0	76	91	3	0.1	307	0	0.0	3	12	0.1	0.05	0.17
9 GRAVITY THICKENER	50.0	92	110	3	0.2	319	0	0.0	3	13	0.1	0.03	0.09
10 CHEMICAL SLUDGE PUMPING-DILUTE	1.0	15	18	0	1.3	38	0	0.0	2	4	1.1	0.40	1.40
10 CHEMICAL SLUDGE PUMPING-DILUTE	5.0	29	35	1	2.3	77	0	0.0	3	6	0.3	0.12	0.42
10 CHEMICAL SLUDGE PUMPING-DILUTE	10.0	41	49	2	3.2	111	0	0.0	4	9	0.2	0.09	0.32
10 CHEMICAL SLUDGE PUMPING-DILUTE	25.0	51	61	5	3.7	144	0	0.0	5	11	0.1	0.04	0.15
10 CHEMICAL SLUDGE PUMPING-DILUTE	50.0	54	65	10	3.8	162	0	0.0	6	12	0.1	0.02	0.08
11 DECANTER CENTRIFUGE	1.0	156	187	45	1.7	772	0	0.0	11	29	7.9	2.90	10.15
11 DECANTER CENTRIFUGE	5.0	162	194	51	2.0	814	0	0.0	12	30	1.6	0.60	2.10
11 DECANTER CENTRIFUGE	10.0	190	228	83	3.1	1014	0	0.0	16	38	1.0	0.38	1.33
11 DECANTER CENTRIFUGE	25.0	256	307	166	5.8	1493	0	0.0	26	55	0.6	0.22	0.77
11 DECANTER CENTRIFUGE	50.0	332	398	285	9.2	2041	0	0.0	38	76	0.4	0.15	0.53
12 SLUDGE HAULING	1.0	0	0	0	0.5	73	0	0.0	1	1	0.3	0.10	0.35
12 SLUDGE HAULING	5.0	0	0	0	1.2	262	0	0.0	4	4	0.2	0.08	0.28
12 SLUDGE HAULING	10.0	0	0	0	2.0	500	0	0.0	7	7	0.2	0.07	0.25
12 SLUDGE HAULING	25.0	0	0	0	4.3	1164	0	0.0	16	16	0.2	0.06	0.22
12 SLUDGE HAULING	50.0	0	0	0	8.5	2376	0	0.0	32	32	0.2	0.06	0.22

TOTAL COST FOR COMPONENTS 1 THRU 12: CLARIFICATION AND CHLORINATION

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL THOU $	COST CTS/ K GAL	FACTORS* $ PER CAPITA	$ PER HOME
CLARIFICATION AND CHLORINATION	1.0	814	977	228	9.3	4039	0	96.0	67	148	40.5	14.80	51.80
CLARIFICATION AND CHLORINATION	5.0	1658	1992	706	16.6	5308	0	479.7	145	310	17.0	6.20	21.70
CLARIFICATION AND CHLORINATION	10.0	2628	3153	1320	24.8	6868	0	954.5	240	500	13.7	5.00	17.50
CLARIFICATION AND CHLORINATION	25.0	5096	6115	2969	43.1	11135	0	2244.2	495	999	10.9	4.00	13.99
CLARIFICATION AND CHLORINATION	50.0	8294	9954	5648	65.3	16857	0	4488.2	905	1723	9.4	3.45	12.06

THE FOLLOWING 7 PROCESSES ARE COST COMPONENTS OF MIXED MEDIA FILTRATION

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL THOU $	COST CTS/ K GAL	FACTORS* $ PER CAPITA	$ PER HOME
13 GRAVITY FILTRATION STRUCTURE	1.0	151	181	12	1.3	1874	0	0.0	20	37	10.1	3.70	12.95
13 GRAVITY FILTRATION STRUCTURE	5.0	432	518	38	4.6	2255	0	0.0	28	77	4.2	1.54	5.39
13 GRAVITY FILTRATION STRUCTURE	10.0	758	910	68	8.5	2768	0	0.0	38	124	3.4	1.24	4.34
13 GRAVITY FILTRATION STRUCTURE	25.0	1495	1794	140	17.8	4337	0	0.0	65	234	2.6	0.94	3.28
13 GRAVITY FILTRATION STRUCTURE	50.0	2392	2870	237	30.2	7598	0	0.0	113	384	2.1	0.77	2.69

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTOR**			
										THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
14 FILTRA-HYDRAULIC SURFACE WASH	1.0	11	13	3	0.0	55	0	0.0	1	2	0.5	0.20	0.70
14 FILTRA-HYDRAULIC SURFACE WASH	5.0	27	32	13	0.0	118	0	0.0	2	5	0.3	0.10	0.35
14 FILTRA-HYDRAULIC SURFACE WASH	10.0	46	55	25	0.0	181	0	0.0	3	8	0.2	0.08	0.28
14 FILTRA-HYDRAULIC SURFACE WASH	25.0	86	103	57	0.0	249	0	0.0	4	14	0.2	0.06	0.20
14 FILTRA-HYDRAULIC SURFACE WASH	50.0	153	184	114	0.1	311	0	0.0	7	24	0.1	0.05	0.17
15 FILTRA-BACKWASH PUMPING SYSTEM	1.0	79	95	4	0.0	5	0	0.0	0	9	2.5	0.90	3.15
15 FILTRA-BACKWASH PUMPING SYSTEM	5.0	261	313	21	0.1	12	0	0.0	1	31	1.7	0.62	2.17
15 FILTRA-BACKWASH PUMPING SYSTEM	10.0	451	541	41	0.1	20	0	0.0	2	53	1.5	0.53	1.86
15 FILTRA-BACKWASH PUMPING SYSTEM	25.0	743	892	98	0.3	31	0	0.0	4	88	1.0	0.35	1.23
15 FILTRA-BACKWASH PUMPING SYSTEM	50.0	1072	1286	195	0.5	45	0	0.0	7	128	0.7	0.26	0.90
16 MEDIA-MIXED MEDIA FILTRATION	1.0	9	11	0	0.0	0	0	0.0	0	1	0.3	0.10	0.35
16 MEDIA-MIXED MEDIA FILTRATION	5.0	29	35	0	0.0	0	0	0.0	0	3	0.2	0.06	0.21
16 MEDIA-MIXED MEDIA FILTRATION	10.0	53	64	0	0.0	0	0	0.0	0	6	0.2	0.06	0.21
16 MEDIA-MIXED MEDIA FILTRATION	25.0	113	136	0	0.0	0	0	0.0	0	13	0.1	0.05	0.18
16 MEDIA-MIXED MEDIA FILTRATION	50.0	204	245	0	0.0	0	0	0.0	0	23	0.1	0.05	0.16
17 SUPPLY PUMPING	1.0	31	37	57	0.4	527	0	0.0	7	10	2.7	1.00	3.50
17 SUPPLY PUMPING	5.0	53	64	282	1.1	654	0	0.0	16	22	1.2	0.44	1.54
17 SUPPLY PUMPING	10.0	80	96	564	1.9	807	0	0.0	27	36	1.0	0.36	1.26
17 SUPPLY PUMPING	25.0	151	181	1326	4.4	1192	0	0.0	56	73	0.8	0.29	1.02
17 SUPPLY PUMPING	50.0	269	323	2650	9.1	1790	0	0.0	106	136	0.7	0.27	0.95
18 POLYMER FEED SYSTEMS	1.0	22	26	23	0.2	198	0	0.2	4	6	1.6	0.60	2.10
18 POLYMER FEED SYSTEMS	5.0	23	28	23	0.2	199	0	1.0	7	10	0.5	0.20	0.70
18 POLYMER FEED SYSTEMS	10.0	27	32	23	0.3	200	0	1.9	11	14	0.4	0.14	0.49
18 POLYMER FEED SYSTEMS	25.0	58	70	46	0.5	400	0	4.6	24	31	0.3	0.12	0.43
18 POLYMER FEED SYSTEMS	50.0	95	114	69	0.8	602	0	8.9	45	56	0.3	0.11	0.39
19 ALUM FEED SYSTEM	1.0	23	28	9	0.2	284	0	19.3	5	8	2.2	0.80	2.80
19 ALUM FEED SYSTEM	5.0	33	40	10	0.2	296	0	95.5	11	15	0.8	0.30	1.05
19 ALUM FEED SYSTEM	10.0	46	55	12	0.2	310	0	191.0	18	23	0.6	0.23	0.80
19 ALUM FEED SYSTEM	25.0	76	91	16	0.2	351	0	446.8	38	47	0.5	0.19	0.66
19 ALUM FEED SYSTEM	50.0	116	139	23	0.2	428	0	893.5	72	85	0.5	0.17	0.59

TOTAL COST FOR COMPONENTS 13 THRU 19: MIXED MEDIA FILTRATION

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
MIXED MEDIA FILTRATION	1.0	371	446	108	2.1	2943	0	19.5	37	73	20.0	7.30	25.55
MIXED MEDIA FILTRATION	5.0	983	1181	387	6.2	3534	0	96.4	65	163	8.9	3.26	11.41
MIXED MEDIA FILTRATION	10.0	1676	2013	733	11.1	4286	0	192.9	99	264	7.2	2.64	9.24
MIXED MEDIA FILTRATION	25.0	3126	3754	1683	23.3	6560	0	451.3	191	500	5.5	2.00	7.00
MIXED MEDIA FILTRATION	50.0	4942.	5931	3288	40.9	10774	0	902.4	350	836	4.6	1.67	5.85

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     COMPONENT                         AVE   CONSTN  CAPITAL   ELEC   MAINT                FUEL             TOTAL  *TOTAL ANNUAL COST FACTORS*
        OR                             FLOW   COST    COST     THOU   MAT'L   LABOR      MIL      CHEM    O&M/YR  THOU   CTS/   $ PER    $ PER
      SYSTEM                           MGD   THOU $  THOU $   KWH/YR  K$/YR   HR/YR    BTU/YR    TN/YR   THOU $   $    K GAL  CAPITA    HOME

                THE FOLLOWING  3 PROCESSES ARE COST COMPONENTS OF ACTIVATED CARBON ADSORPTION

 20 GRANULAR ACT CARBON CONTACTORS     1.0     217     260       34     1.6    1872         0      0.0      21     46   12.6    4.60    16.10
 20 GRANULAR ACT CARBON CONTACTORS     5.0     595     714       64     5.7    2304         0      0.0      31     98    5.4    1.96     6.86
 20 GRANULAR ACT CARBON CONTACTORS    10.0    1026    1231      100    10.4    2870         0      0.0      42    158    4.3    1.58     5.53
 20 GRANULAR ACT CARBON CONTACTORS    25.0    1982    2378      184    21.5    4528         0      0.0      72    296    3.2    1.18     4.14
 20 GRANULAR ACT CARBON CONTACTORS    50.0    3071    3685      294    35.7    7808         0      0.0     123    471    2.6    0.94     3.30

 21 GRANULAR ACTIVATED CARBON          1.0      16      19        0     0.0       0         0      0.0       0      2    0.5    0.20     0.70
 21 GRANULAR ACTIVATED CARBON          5.0      76      91        0     0.0       0         0      0.0       0      9    0.5    0.18     0.63
 21 GRANULAR ACTIVATED CARBON         10.0     151     181        0     0.0       0         0      0.0       0     17    0.5    0.17     0.59
 21 GRANULAR ACTIVATED CARBON         25.0     352     422        0     0.0       0         0      0.0       0     40    0.4    0.16     0.56
 21 GRANULAR ACTIVATED CARBON         50.0     698     838        0     0.0       0         0      0.0       0     79    0.4    0.16     0.55

 22 GRAN ACT CARBON REGENERATION       1.0     581     697      163     1.2     208       553      1.5      12     78   21.4    7.80    27.30
 22 GRAN ACT CARBON REGENERATION       5.0     612     734      199     2.3     607      2442      7.6      32    101    5.5    2.02     7.07
 22 GRAN ACT CARBON REGENERATION      10.0     759     911      236     3.4    1074      4671     15.2      55    141    3.9    1.41     4.94
 22 GRAN ACT CARBON REGENERATION      25.0    1115    1338      282     4.7    2083      9360     35.9     109    235    2.6    0.94     3.29
 22 GRAN ACT CARBON REGENERATION      50.0    1604    1925      337     6.3    3821     17252     71.6     199    381    2.1    0.76     2.67

                    TOTAL COST FOR COMPONENTS  20 THRU  22:   ACTIVATED CARBON ADSORPTION

ACTIVATED CARBON ADSORPTION            1.0     935    1121      197     2.8    2080       553      1.5      33    126   34.5   12.60    44.10
ACTIVATED CARBON ADSORPTION            5.0    1474    1769      263     8.0    2911      2442      7.6      63    208   11.4    4.16    14.56
ACTIVATED CARBON ADSORPTION           10.0    2224    2670      336    13.9    3944      4671     15.2      97    316    8.7    3.16    11.06
ACTIVATED CARBON ADSORPTION           25.0    3965    4757      466    26.1    6611      9360     35.9     181    571    6.3    2.28     7.99
ACTIVATED CARBON ADSORPTION           50.0    6177    7413      631    42.0   11629     17252     71.6     322    931    5.1    1.86     6.52

 23 REVERSE OSMOSIS                    1.0     849    1019     2524    91.3    1938         0      0.0     186    282   77.3   28.20    98.70
 23 REVERSE OSMOSIS                    5.0    3216    3859    11993   369.2    2286         0      0.0     752   1116   61.2   22.32    78.12
 23 REVERSE OSMOSIS                   10.0    6117    7340    23823   711.4    2694         0      0.0    1453   2146   58.8   21.46    75.11
 23 REVERSE OSMOSIS                   25.0   14451   17341    59260  1705.6    3741         0      0.0    3521   5158   56.5   20.63    72.21
 23 REVERSE OSMOSIS                   50.0   27281   32737   118064  3277.2    5007         0      0.0    6869   9959   54.6   19.92    69.71

           ***** TREATMENT SYSTEM COST SUMMARIES INCLUDING YARD PIPING AT 15 PERCENT OF CONSTRUCTION COST *****

UPGRADED WATER TRT + R OSMOSIS         1.0    3096    3715     3057   105.5   11000       553    117.0     323    629  172.3   62.90   220.15
UPGRADED WATER TRT + R OSMOSIS         5.0    7813    9379    13349   400.0   14039      2442    583.7    1025   1797   98.5   35.94   125.79
UPGRADED WATER TRT + R OSMOSIS        10.0   13562   16277    26212   761.1   17792      4671   1162.6    1889   3226   88.4   32.26   112.91
UPGRADED WATER TRT + R OSMOSIS        25.0   28805   34568    64378  1798.1   28047      9360   2731.4    4388   7228   79.2   28.91   101.19
UPGRADED WATER TRT + R OSMOSIS        50.0   50786   60945   127631  3425.4   44267     17252   5462.3    8446  13449   73.7   26.90    94.14
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DESIGN CRITERIA AND UNIT PROCESS SIZES

PROCESS OR COMPONENT	DESIGN FLOW,MGD					
	AVERAGE:	1.0	5.0	10.0	25.0	50.0
	PEAK:	1.0	5.0	10.0	25.0	50.0
1 RAW WATER PUMPING, FIRM CAPACITY, MGD INCLUDES SCREENING & ONE STANDBY PUMP EQUAL TO LARGEST UNIT		1.3	6.3	12.5	29.4	58.8
2 RAPID MIX BASIN, VOLUME, CU FT NUMBER OF UNITS 1 MIN DETENTION TIME AT AVERAGE FLOW		116.0 1	580.0 1	1160.0 1	2729.0 1	5459.0 1
3 ALUM FEED SYSTEM-DRY ALUM, CAPACITY, LBS/HR ALUM COAGULATION, CAPACITY=60 MG/L, AVG=40 MG/L		26.3	130.0	260.0	613.0	1224.0
4 POLYMER FEED SYSTEMS, FEED CAPACITY/UNIT, LBS/DAY NUMBER OF UNITS COAGULANT AID, CAPACITY=1 MG/L, AVG=0.1 MG/L DOSE		10.4 1	52.5 1	104.0 1	125.0 2	163.0 3
5 FLOCCULATION, TOTAL BASIN VOLUME, CU FT HORIZONTAL PADDLE, G=80, DETENTION TIME=30 MIN AT AVG FLOW		3475.0	17375.0	34750.0	81764.0	163529.0
6 CIRCULAR CLARIFIER, SURFACE AREA/UNIT, SQ FT NUMBER OF UNITS OVERFLOW RATE=950 GAL/DAY/SQ FT		658.0 2	3288.0 2	6575.0 2	7741.0 4	15529.0 4
7 CHLORINE FEED SYSTEMS, FEED CAPACITY, LB/DAY CAPACITY=10 MG/L DOSE		105.0	523.0	1044.0	2456.0	4912.0
8 CHEMICAL SLUDGE PUMPING, FIRM PUMPING CAPACITY, GPM CAPACITY=40 MG/L AT PEAK FLOW AND 0.5% SOLIDS		15.0	70.0	140.0	327.0	654.0
9 GRAVITY THICKENER, SURFACE AREA/UNIT, SQ FT NUMBER OF UNITS ALUM SLUDGE,OVERFLOW RATE=1000 GPD/SQ FT WITH 0.5% SOLIDS IN		78.0 1	78.0 1	100.0 1	235.0 1	470.0 1
10 CHEMICAL SLUDGE PUMPING, FIRM PUMPING CAPACITY, GPM THICKENED ALUM SLUDGE, 1% SOLIDS		4.0	18.0	35.0	81.0	164.0
11 DECANTER CENTRUFUGE, CENTRIFUGE CAPACITY, GPM NUMBER OF UNITS ALUM SLUDGE AT 1% SOLIDS INFLUENT CONCENTRATION		13.0 1	16.0 1	31.0 1	74.0 1	147.0 1
12 SLUDGE HAULING, ANNUAL VOLUME, CU YD ALUM SLUDGE, CONCENTRATED TO 20% SOLIDS		451.0	2263.0	4513.0	10624.0	21294.0
13 GRAVITY FILTRATION STRUCTURE, TOTAL FILTER AREA, SQ FT MIXED MEDIA FILTER, FILTRATION RATE=5 GPM/SQ FT, WATER & AWT		174.0	868.0	1738.0	4082.0	8165.0
14 FILTRA-HYDRAULIC SURFACE WASH, INDIVIDUAL FILTER AREA, SQ FT NUMBER OF UNITS MIXED MEDIA FILTER, FILTRATION RATE=5 GPM/SQ FT, WATER & AWT		86.0 2	218.0 4	289.0 6	511.0 8	816.0 10
15 FILTRA-BACKWASH PUMPING SYSTEM, FIRM PUMPING CAPACITY, GPM NUMBER OF UNITS MIXED MEDIA FILTER,WATER&AWT, BACKWASH CAPACITY=18 GPM/SQ FT		1550.0 2	3913.0 4	5200.0 6	9188.0 8	14706.0 10

DESIGN CRITERIA AND UNIT PROCESS SIZES

PROCESS OR COMPONENT					
DESIGN FLOW,MGD					
AVERAGE:	1.0	5.0	10.0	25.0	50.0
PEAK:	1.0	5.0	10.0	25.0	50.0
16 MEDIA-MIXED MEDIA FILTRATION, TOTAL FILTER AREA, SQ FT MIXED MEDIA FILTER, WATER & AWT, FILTRATION RATE=5 GPM/SG FT	174.0	868.0	1738.0	4082.0	8165.0
17 SUPPLY PUMPING,PUMPING RATE, MGD GRAVITY FILTER OR AWT UPFLOW CARBON CONTACTOR SUPPLY	1.3	6.3	12.5	29.4	58.8
18 POLYMER FEED SYSTEMS, FEED CAPACITY/UNIT, LBS/DAY	10.4	52.5	104.0	125.0	163.0
NUMBER OF UNITS FILTRATION AND COAGULANT AID,1 MG/L CAPACITY,0.1 MG/L AVG	1	1	1	2	3
19 ALUM FEED SYSTEM-DRY ALUM, CAPACITY, LBS/HR MIXED MEDIA FILTER AID, 20 MG/L CAPACITY, 10 MG/L AVG	8.8	43.6	87.2	204.0	408.0
20 GRANULAR ACT CARBON CONTACTORS, TOTAL CONTACTOR AREA,SQ FT GRAVITY DOWNFLOW, CONTACT TIME 7.5 MIN, RATE 5 GPM/SQ FT	175.0	875.0	1750.0	4112.0	8235.0
21 GRANULAR ACTIVATED CARBON, TOTAL WEIGHT OF CARBON, LBS CONTACT TIME=7.5 MIN, CARBON WEIGHT=30 LB/ CU FT	26250.0	131250.0	262500.0	617650.0	1235300.0
22 GRANULAR CARBON REGENERATION, HEARTH AREA, SQ FT 40% DOWNTIME,40 LB/SQ FT/DAY; REMOVAL=0.5 LB COD/LB CARBON	28.0	35.0	70.0	164.0	327.0
23 REVERSE OSMOSIS, PRODUCT WATER FLOW RATE, MGD WATER RECOVERY: 1,5,10 MGD, 80%; 25,50 MGD, 85%	1.0	5.0	10.0	25.C	50.0

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COST INFORMATION:

 COSTS PRESENTED AS DOLLARS ARE CURRENT AS OF JANUARY 1977

 CAPITAL COST FACTORS:  INTEREST RATE(%)    =7
                        NUMBER OF YEARS     =20
                        ENGINEERING(%)      =10    (PER CENT OF CONSTRUCTION COST)
                        LEGAL,FISCAL(%)     =3     (PER CENT OF CONSTRUCTION COST)
                        INT DURING CONST(%)=7      (PER CENT OF CONSTRUCTION COST)
                        YARD PIPING FACTOR =15     (PER CENT OF CONSTRUCTION COST)

 PER CAPITA COSTS:      GAL/PERSON/DAY      =100
                        PEOPLE/HOME         =3.5

 UNIT COST FACTORS:     ELECTRICITY,$/KWH  =0.03
                        LABOR,$/HR          =10
                        FUEL,$/MIL BTU      =3

 CHEMICAL COSTS:        LIME,$/TON          =52
                        ALUM,$/TON          =75
                        CHLORINE,$/TON      =220
                        POLYMER,$/LB        =2

 CONSTN COST INDEXES:   EXCAVATION          =220.6  (ENR SKILLED LABOR)
                        MANUFACTURED EQUIP =195.7  (BLS #114)
                        CONCRETE            =193.1  (BLS #132)
                        STEEL               =221.3  (BLS #101.3)
                        LABOR               =220.6  (ENR SKILLED LABOR)
                        PIPES & VALVES      =209.4  (BLS #114.901)
                        HOUSING             =30     (ACTUAL BLDG COST,$/SQ FT)
                        WHOLESALE PRICE     =188.0  (BLS ALL COMMODITIES)

 EPA CONSTN INDEXES:    SCCT(5 MGD PLANT)  =121    (NATIONAL INDEX VALUE)
                        LCAT(50 MGD PLANT) =132    (NATIONAL INDEX VALUE)
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COST SUMMARY

WASTEWATER TREATMENT SYSTEMS - INCREASED RELIABILITY

SECONDARY TREATMENT

ADVANCED WASTEWATER TREATMENT

EARTHEN STORAGE

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS* THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME

THE FOLLOWING 16 PROCESSES ARE COST COMPONENTS OF SECONDARY TREATMENT-ACT SLUDGE

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS* THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
1 RAW WASTEWATER PUMPING	1.0	215	258	70	0.6	1030	0	0.0	13	37	10.1	3.70	12.95
1 RAW WASTEWATER PUMPING	5.0	720	864	269	1.4	1195	0	0.0	21	103	5.6	2.06	7.21
1 RAW WASTEWATER PUMPING	10.0	1284	1541	516	2.6	1458	0	0.0	33	178	4.9	1.78	6.23
1 RAW WASTEWATER PUMPING	25.0	2462	2954	1231	7.0	2308	0	0.0	67	346	3.8	1.38	4.84
1 RAW WASTEWATER PUMPING	50.0	3911	4693	2347	13.0	3648	0	0.0	120	563	3.1	1.13	3.94
2 AERATED GRIT CHAMBER	1.0	131	157	4	2.1	954	0	0.0	12	27	7.4	2.70	9.45
2 AERATED GRIT CHAMBER	5.0	312	374	19	3.0	1869	0	0.0	22	57	3.1	1.14	3.99
2 AERATED GRIT CHAMBER	10.0	416	499	36	4.4	3013	0	0.0	36	83	2.3	0.83	2.91
2 AERATED GRIT CHAMBER	25.0	740	888	79	10.0	6445	0	0.0	77	161	1.8	0.64	2.25
2 AERATED GRIT CHAMBER	50.0	1026	1231	136	18.0	12165	0	0.0	144	260	1.4	0.52	1.82
3 CIRCULAR PRIMARY CLARIFIER	1.0	240	288	10	0.5	287	0	0.0	4	31	8.5	3.10	10.85
3 CIRCULAR PRIMARY CLARIFIER	5.0	536	643	12	1.3	582	0	0.0	8	69	3.8	1.38	4.83
3 CIRCULAR PRIMARY CLARIFIER	10.0	894	1073	24	2.6	1163	0	0.0	15	116	3.2	1.16	4.06
3 CIRCULAR PRIMARY CLARIFIER	25.0	1776	2131	31	5.4	2065	0	0.0	27	228	2.5	0.91	3.19
3 CIRCULAR PRIMARY CLARIFIER	50.0	3112	3734	42	9.3	3130	0	0.0	42	394	2.2	0.79	2.76
4 AERATION BASIN	1.0	223	268	0	0.0	0	0	0.0	0	25	6.8	2.50	8.75
4 AERATION BASIN	5.0	887	1064	0	0.0	0	0	0.0	0	100	5.5	2.00	7.00
4 AERATION BASIN	10.0	1397	1676	0	0.0	0	0	0.0	0	158	4.3	1.58	5.53
4 AERATION BASIN	25.0	2810	3372	0	0.0	0	0	0.0	0	318	3.5	1.27	4.45
4 AERATION BASIN	50.0	4223	5068	0	0.0	0	0	0.0	0	478	2.6	0.96	3.35
5 MECHANICAL AERATION EQUIPMENT	1.0	177	212	600	5.7	2111	0	0.0	45	65	17.8	6.50	22.75
5 MECHANICAL AERATION EQUIPMENT	5.0	654	785	3000	10.5	4686	0	0.0	147	221	12.1	4.42	15.47
5 MECHANICAL AERATION EQUIPMENT	10.0	1003	1204	5000	14.0	6574	0	0.0	230	344	9.4	3.44	12.04
5 MECHANICAL AERATION EQUIPMENT	25.0	1979	2375	12500	22.6	11571	0	0.0	513	737	8.1	2.95	10.32
5 MECHANICAL AERATION EQUIPMENT	50.0	2748	3298	23350	26.9	12979	0	0.0	857	1168	6.4	2.34	8.18
6 CIRCULAR SECONDARY CLARIFIER	1.0	265	318	10	0.6	313	0	0.0	4	34	9.3	3.40	11.90
6 CIRCULAR SECONDARY CLARIFIER	5.0	657	788	13	1.7	693	0	0.0	9	83	4.5	1.66	5.81
6 CIRCULAR SECONDARY CLARIFIER	10.0	1095	1314	26	3.3	1385	0	0.0	18	142	3.9	1.42	4.97
6 CIRCULAR SECONDARY CLARIFIER	25.0	2240	2688	35	6.8	2470	0	0.0	33	287	3.1	1.15	4.02
6 CIRCULAR SECONDARY CLARIFIER	50.0	3962	4754	60	12.7	4393	0	0.0	58	507	2.8	1.01	3.55
7 CHLORINE FEED SYSTEMS	1.0	20	24	4	1.8	410	0	15.3	9	11	3.0	1.10	3.85
7 CHLORINE FEED SYSTEMS	5.0	57	68	11	2.4	749	0	76.3	27	33	1.8	0.66	2.31
7 CHLORINE FEED SYSTEMS	10.0	92	110	18	3.1	1129	0	152.4	48	58	1.6	0.58	2.03
7 CHLORINE FEED SYSTEMS	25.0	142	170	33	4.6	2020	0	381.1	110	126	1.4	0.50	1.76
7 CHLORINE FEED SYSTEMS	50.0	175	210	43	5.4	2907	0	761.9	203	223	1.2	0.45	1.56

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL	COST	FACTORS*	
										THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
8 CHLORINE CONTACT BASIN	1.0	29	35	0	0.0	0	0	0.0	0	3	0.8	0.30	1.05
8 CHLORINE CONTACT BASIN	5.0	88	106	0	0.0	0	0	0.0	0	10	0.5	0.20	0.70
8 CHLORINE CONTACT BASIN	10.0	149	179	0	0.0	0	0	0.0	0	17	0.5	0.17	0.59
8 CHLORINE CONTACT BASIN	25.0	263	316	0	0.0	0	0	0.0	0	30	0.3	0.12	0.42
8 CHLORINE CONTACT BASIN	50.0	410	492	0	0.0	0	0	0.0	0	46	0.3	0.09	0.32
9 RETURN ACT SLUDGE PUMPING	1.0	86	103	11	0.5	733	0	0.0	8	18	4.9	1.80	6.30
9 RETURN ACT SLUDGE PUMPING	5.0	203	244	43	0.9	921	0	0.0	11	34	1.9	0.68	2.38
9 RETURN ACT SLUDGE PUMPING	10.0	312	374	81	1.4	1154	0	0.0	15	50	1.4	0.50	1.75
9 RETURN ACT SLUDGE PUMPING	25.0	457	548	193	3.1	1691	0	0.0	26	78	0.9	0.31	1.09
9 RETURN ACT SLUDGE PUMPING	50.0	556	667	365	6.4	2168	0	0.0	39	102	0.6	0.20	0.71
10 WASTE SLUDGE PUMPING	1.0	64	77	0	1.3	108	0	0.0	2	9	2.5	0.90	3.15
10 WASTE SLUDGE PUMPING	5.0	141	169	1	1.8	128	0	0.0	3	19	1.0	0.38	1.33
10 WASTE SLUDGE PUMPING	10.0	216	259	2	2.4	151	0	0.0	4	28	0.8	0.28	0.98
10 WASTE SLUDGE PUMPING	25.0	331	397	5	4.3	216	0	0.0	7	44	0.5	0.18	0.62
10 WASTE SLUDGE PUMPING	50.0	359	431	10	7.3	306	0	0.0	11	52	0.3	0.10	0.36
11 GRAVITY THICKENER	1.0	135	162	3	0.1	300	0	0.0	3	18	4.9	1.80	6.30
11 GRAVITY THICKENER	5.0	212	254	6	0.2	606	0	0.0	6	30	1.6	0.60	2.10
11 GRAVITY THICKENER	10.0	246	295	6	0.3	623	0	0.0	7	35	1.0	0.35	1.23
11 GRAVITY THICKENER	25.0	341	409	8	0.5	676	0	0.0	8	47	0.5	0.19	0.66
11 GRAVITY THICKENER	50.0	482	578	10	0.8	765	0	0.0	9	64	0.4	0.13	0.45
12 FLOTATION THICKENER	1.0	PROCESS NOT INCLUDED FOR THIS PLANT CAPACITY											
12 FLOTATION THICKENER	5.0	292	350	396	0.2	1678	0	0.0	29	62	3.4	1.24	4.34
12 FLOTATION THICKENER	10.0	376	451	726	0.3	3033	0	0.0	52	95	2.6	0.95	3.33
12 FLOTATION THICKENER	25.0	467	560	1112	0.4	4571	0	0.0	79	132	1.4	0.53	1.85
12 FLOTATION THICKENER	50.0	757	908	1807	0.7	7246	0	0.0	127	213	1.2	0.43	1.49
13 ANAEROBIC DIGESTER	1.0	231	277	47	2.2	1174	2116	0.0	22	48	13.2	4.80	16.80
13 ANAEROBIC DIGESTER	5.0	686	823	234	4.7	2153	10580	0.0	65	143	7.8	2.86	10.01
13 ANAEROBIC DIGESTER	10.0	1009	1211	391	6.5	2967	21160	0.0	111	225	6.2	2.25	7.88
13 ANAEROBIC DIGESTER	25.0	1943	2332	977	11.6	5993	52900	0.0	260	480	5.3	1.92	6.72
13 ANAEROBIC DIGESTER	50.0	3405	4086	1824	16.0	10200	105800	0.0	490	876	4.8	1.75	6.13
14 SAND DRYING BEDS	1.0	77	92	0	2.6	688	0	0.0	9	18	4.9	1.80	6.30
14 SAND DRYING BEDS	5.0	352	422	0	13.0	3854	0	0.0	52	92	5.0	1.84	6.44
14 SAND DRYING BEDS	10.0	683	820	0	26.0	9329	0	0.0	119	196	5.4	1.96	6.86
14 SAND DRYING BEDS	25.0	1619	1943	0	65.1	29793	0	0.0	363	546	6.0	2.18	7.64
14 SAND DRYING BEDS	50.0	3250	3900	0	130.1	39901	0	0.0	529	897	4.9	1.79	6.28

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS*			
										THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
15 SLUDGE HAULING	1.0	0	0	0	0.7	102	0	0.0	2	2	0.5	0.20	0.70
15 SLUDGE HAULING	5.0	0	0	0	1.7	408	0	0.0	6	6	0.3	0.12	0.42
15 SLUDGE HAULING	10.0	0	0	0	3.1	799	0	0.0	11	11	0.3	0.11	0.39
15 SLUDGE HAULING	25.0	0	0	0	7.3	2024	0	0.0	28	28	0.3	0.11	0.39
15 SLUDGE HAULING	50.0	0	0	0	14.5	4172	0	0.0	56	56	0.3	0.11	0.39
16 YARD MAINTENANCE	1.0	0	0	0	1.6	2100	0	0.0	23	23	6.3	2.30	8.05
16 YARD MAINTENANCE	5.0	0	0	0	1.9	2385	0	0.0	26	26	1.4	0.52	1.82
16 YARD MAINTENANCE	10.0	0	0	0	2.5	2985	0	0.0	32	32	0.9	0.32	1.12
16 YARD MAINTENANCE	25.0	0	0	0	4.1	4557	0	0.0	50	50	0.5	0.20	0.70
16 YARD MAINTENANCE	50.0	0	0	0	5.2	6311	0	0.0	68	68	0.4	0.14	0.48
TOTAL COST FOR COMPONENTS 1 THRU 16! SECONDARY TREATMENT-ACT SLUDGE													
SECONDARY TREATMENT-ACT SLUDGE	1.0	2171	2605	759	20.1	10310	2116	15.3	156	369	101.1	36.90	129.15
SECONDARY TREATMENT-ACT SLUDGE	5.0	6660	7991	4004	44.6	21907	10580	76.3	432	1088	59.6	21.76	76.16
SECONDARY TREATMENT-ACT SLUDGE	10.0	10541	12650	6826	72.5	35763	21160	152.4	731	1768	48.4	17.68	61.88
SECONDARY TREATMENT-ACT SLUDGE	25.0	20200	24240	16204	152.7	76400	52900	381.1	1648	3638	39.9	14.55	50.93
SECONDARY TREATMENT-ACT SLUDGE	50.0	32625	39151	29994	266.5	110291	105800	761.9	2753	5967	32.7	11.93	41.77
THE FOLLOWING 7 PROCESSES ARE COST COMPONENTS OF MIXED MEDIA FILTRATION-SEC EFF													
17 GRAVITY FILTRATION STRUCTURE	1.0	271	325	23	2.7	2030	0	0.0	24	55	15.1	5.50	19.25
17 GRAVITY FILTRATION STRUCTURE	5.0	686	823	61	7.7	2648	0	0.0	36	114	6.2	2.28	7.98
17 GRAVITY FILTRATION STRUCTURE	10.0	1144	1373	105	13.3	3507	0	0.0	52	182	5.0	1.82	6.37
17 GRAVITY FILTRATION STRUCTURE	25.0	2165	2598	211	26.9	6560	0	0.0	99	344	3.8	1.38	4.82
17 GRAVITY FILTRATION STRUCTURE	50.0	3125	3750	324	42.0	12518	0	0.0	177	531	2.9	1.06	3.72
18 FILTRA-HYDRAULIC SURFACE WASH	1.0	23	28	4	0.0	56	0	0.0	1	4	1.1	0.40	1.40
18 FILTRA-HYDRAULIC SURFACE WASH	5.0	53	64	17	0.0	175	0	0.0	2	8	0.4	0.16	0.56
18 FILTRA-HYDRAULIC SURFACE WASH	10.0	77	92	33	0.0	241	0	0.0	3	12	0.3	0.12	0.42
18 FILTRA-HYDRAULIC SURFACE WASH	25.0	141	169	81	0.1	312	0	0.0	6	22	0.2	0.09	0.31
18 FILTRA-HYDRAULIC SURFACE WASH	50.0	246	295	162	0.1	375	0	0.0	9	37	0.2	0.07	0.26
19 FILTRA-BACKWASH PUMPING SYSTEM	1.0	186	223	6	0.0	6	0	0.0	0	21	5.8	2.10	7.35
19 FILTRA-BACKWASH PUMPING SYSTEM	5.0	490	588	28	0.1	18	0	0.0	1	57	3.1	1.14	3.99
19 FILTRA-BACKWASH PUMPING SYSTEM	10.0	751	901	55	0.2	26	0	0.0	2	87	2.4	0.87	3.05
19 FILTRA-BACKWASH PUMPING SYSTEM	25.0	1152	1382	138	0.4	40	0	0.0	5	135	1.5	0.54	1.89
19 FILTRA-BACKWASH PUMPING SYSTEM	50.0	1681	2017	277	0.7	57	0	0.0	10	200	1.1	0.40	1.40

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS* THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
20 MEDIA-MIXED MEDIA FILTRATION	1.0	18	22	0	0.0	0	0	0.0	0	2	0.5	0.20	0.70
20 MEDIA-MIXED MEDIA FILTRATION	5.0	48	58	0	0.0	0	0	0.0	0	5	0.3	0.10	0.35
20 MEDIA-MIXED MEDIA FILTRATION	10.0	83	100	0	0.0	0	0	0.0	0	9	0.2	0.09	0.32
20 MEDIA-MIXED MEDIA FILTRATION	25.0	178	214	0	0.0	0	0	0.0	0	20	0.2	0.08	0.28
20 MEDIA-MIXED MEDIA FILTRATION	50.0	311	373	0	0.0	0	0	0.0	0	35	0.2	0.07	0.25
21 SUPPLY PUMPING	1.0	30	36	45	0.3	520	0	0.0	7	10	2.7	1.00	3.50
21 SUPPLY PUMPING	5.0	47	56	226	0.9	623	0	0.0	14	19	1.0	0.38	1.33
21 SUPPLY PUMPING	10.0	69	83	451	1.6	747	0	0.0	23	31	0.8	0.31	1.09
21 SUPPLY PUMPING	25.0	132	158	1128	3.7	1096	0	0.0	49	64	0.7	0.26	0.90
21 SUPPLY PUMPING	50.0	234	281	2254	7.6	1618	0	0.0	91	118	0.6	0.24	0.83
22 POLYMER FEED SYSTEMS	1.0	44	53	23	0.2	198	0	0.3	4	9	2.5	0.90	3.15
22 POLYMER FEED SYSTEMS	5.0	46	55	23	0.2	198	0	1.5	9	14	0.8	0.28	0.98
22 POLYMER FEED SYSTEMS	10.0	51	61	23	0.3	199	0	3.0	15	21	0.6	0.21	0.74
22 POLYMER FEED SYSTEMS	25.0	67	80	23	0.3	201	0	7.6	33	41	0.4	0.16	0.57
22 POLYMER FEED SYSTEMS	50.0	100	120	46	0.6	403	0	11.4	52	63	0.3	0.13	0.44
23 ALUM FEED SYSTEM	1.0	24	29	9	0.2	284	0	15.3	4	7	1.9	0.70	2.45
23 ALUM FEED SYSTEM	5.0	41	49	10	0.2	293	0	76.2	9	14	0.8	0.28	0.98
23 ALUM FEED SYSTEM	10.0	60	72	11	0.2	304	0	152.4	15	22	0.6	0.22	0.77
23 ALUM FEED SYSTEM	25.0	106	127	15	0.2	341	0	381.1	33	45	0.5	0.18	0.63
23 ALUM FEED SYSTEM	50.0	149	179	21	0.2	405	0	762.1	62	79	0.4	0.16	0.55
TOTAL COST FOR COMPONENTS 17 THRU 23: MIXED MEDIA FILTRATION-SEC EFF													
MIXED MEDIA FILTRATION-SEC EFF	1.0	681	820	110	3.5	3094	0	15.6	40	108	29.6	10.80	37.80
MIXED MEDIA FILTRATION-SEC EFF	5.0	1619	1944	365	9.1	3955	0	77.7	71	231	12.7	4.62	16.17
MIXED MEDIA FILTRATION-SEC EFF	10.0	2567	3081	678	15.5	5024	0	155.5	110	364	10.0	3.64	12.74
MIXED MEDIA FILTRATION-SEC EFF	25.0	4528	5435	1596	31.6	8550	0	388.7	225	671	7.4	2.68	9.39
MIXED MEDIA FILTRATION-SEC EFF	50.0	6720	8064	3084	51.2	15376	0	773.5	401	1063	5.8	2.13	7.44
THE FOLLOWING 14 PROCESSES ARE COST COMPONENTS OF LIME CLARIFICATION													
24 LIME FEEDING	1.0	98	118	20	1.2	1189	0	0.0	14	25	6.8	2.50	8.75
24 LIME FEEDING	5.0	136	163	20	1.2	1639	0	0.0	18	33	1.8	0.66	2.31
24 LIME FEEDING	10.0	164	197	21	1.2	2092	0	0.0	23	42	1.2	0.42	1.47
24 LIME FEEDING	25.0	173	208	27	1.3	2878	0	0.0	31	51	0.6	0.20	0.71
24 LIME FEEDING	50.0	177	212	45	1.6	3208	0	0.0	35	55	0.3	0.11	0.39

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL	COST FACTORS*		
										THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
25 POLYMER FEED SYSTEMS	1.0	44	53	23	0.2	198	0	0.3	4	9	2.5	0.90	3.15
25 POLYMER FEED SYSTEMS	5.0	46	55	23	0.2	198	0	1.5	9	14	0.8	0.28	0.98
25 POLYMER FEED SYSTEMS	10.0	51	61	23	0.3	199	0	3.0	15	21	0.6	0.21	0.74
25 POLYMER FEED SYSTEMS	25.0	67	80	23	0.3	201	0	7.6	33	41	0.4	0.16	0.57
25 POLYMER FEED SYSTEMS	50.0	100	120	46	0.6	403	0	11.4	52	63	0.3	0.13	0.44
26 RAPID MIX	1.0	21	25	32	0.2	470	0	0.0	6	8	2.2	0.80	2.80
26 RAPID MIX	5.0	44	53	157	0.5	468	0	0.0	10	15	0.8	0.30	1.05
26 RAPID MIX	10.0	73	88	315	0.8	469	0	0.0	15	23	0.6	0.23	0.80
26 RAPID MIX	25.0	160	192	787	1.8	499	0	0.0	30	48	0.5	0.19	0.67
26 RAPID MIX	50.0	300	360	1574	3.3	617	0	0.0	57	91	0.5	0.18	0.64
27 FLOCCULATION	1.0	59	71	19	0.6	120	0	0.0	2	9	2.5	0.90	3.15
27 FLOCCULATION	5.0	151	181	70	1.4	191	0	0.0	5	22	1.2	0.44	1.54
27 FLOCCULATION	10.0	250	300	140	2.4	260	0	0.0	9	37	1.0	0.37	1.30
27 FLOCCULATION	25.0	403	484	351	4.6	336	0	0.0	18	64	0.7	0.26	0.90
27 FLOCCULATION	50.0	0	0	702	6.3	476	0	0.0	32	32	0.2	0.06	0.22
28 CIRCULAR CLARIFIER	1.0	228	274	10	0.5	274	0	0.0	3	29	7.9	2.90	10.15
28 CIRCULAR CLARIFIER	5.0	479	575	11	1.2	527	0	0.0	7	61	3.3	1.22	4.27
28 CIRCULAR CLARIFIER	10.0	782	938	14	2.0	802	0	0.0	10	99	2.7	0.99	3.47
28 CIRCULAR CLARIFIER	25.0	1549	1859	29	4.7	1851	0	0.0	24	199	2.2	0.80	2.79
28 CIRCULAR CLARIFIER	50.0	2715	3258	39	8.2	2844	0	0.0	38	346	1.9	0.69	2.42
29 RECARBONATION BASIN	1.0	38	46	0	0.0	0	0	0.0	0	4	1.1	0.40	1.40
29 RECARBONATION BASIN	5.0	84	101	0	0.0	0	0	0.0	0	10	0.5	0.20	0.70
29 RECARBONATION BASIN	10.0	127	152	0	0.0	0	0	0.0	0	14	0.4	0.14	0.49
29 RECARBONATION BASIN	25.0	223	268	0	0.0	0	0	0.0	0	25	0.3	0.10	0.35
29 RECARBONATION BASIN	50.0	371	445	0	0.0	0	0	0.0	0	42	0.2	0.08	0.29
30 RECARB WITH SUBMERGED BURNERS	1.0	274	329	285	4.1	160	13815	0.0	56	87	23.8	8.70	30.45
30 RECARB WITH SUBMERGED BURNERS	5.0		PROCESS NOT INCLUDED FOR THIS PLANT CAPACITY										
30 RECARB WITH SUBMERGED BURNERS	10.0		PROCESS NOT INCLUDED FOR THIS PLANT CAPACITY										
30 RECARB WITH SUBMERGED BURNERS	25.0		PROCESS NOT INCLUDED FOR THIS PLANT CAPACITY										
30 RECARB WITH SUBMERGED BURNERS	50.0		PROCESS NOT INCLUDED FOR THIS PLANT CAPACITY										
31 RECARB WITH STACK GAS	1.0		PROCESS NOT INCLUDED FOR THIS PLANT CAPACITY										
31 RECARB WITH STACK GAS	5.0	155	186	2542	4.2	333	0	0.0	84	102	5.6	2.04	7.14
31 RECARB WITH STACK GAS	10.0	309	371	5084	6.2	558	0	0.0	164	199	5.5	1.99	6.97
31 RECARB WITH STACK GAS	25.0	519	623	12707	10.1	1014	0	0.0	401	460	5.0	1.84	6.44
31 RECARB WITH STACK GAS	50.0	929	1115	25419	13.3	1631	0	0.0	792	897	4.9	1.79	6.28

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O$M/YR THOU $	*TOTAL ANNUAL COST FACTORS*			
										THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
32 RECTANGULAR CLARIFIERS	1.0	88	106	3	0.3	177	0	0.0	2	12	3.3	1.20	4.20
32 RECTANGULAR CLARIFIERS	5.0	241	289	8	0.8	434	0	0.0	5	32	1.8	0.64	2.24
32 RECTANGULAR CLARIFIERS	10.0	395	474	10	1.0	569	0	0.0	7	52	1.4	0.52	1.82
32 RECTANGULAR CLARIFIERS	25.0	803	964	21	2.1	939	0	0.0	12	103	1.1	0.41	1.44
32 RECTANGULAR CLARIFIERS	50.0	1338	1606	42	4.1	1877	0	0.0	24	176	1.0	0.35	1.23
33 CHEMICAL SLUDGE PUMPING-DILUTE	1.0	51	61	1	2.5	84	0	0.0	3	9	2.5	0.90	3.15
33 CHEMICAL SLUDGE PUMPING-DILUTE	5.0	74	89	7	3.4	142	0	0.0	5	13	0.7	0.26	0.91
33 CHEMICAL SLUDGE PUMPING-DILUTE	10.0	102	122	13	4.1	177	0	0.0	6	18	0.5	0.18	0.63
33 CHEMICAL SLUDGE PUMPING-DILUTE	25.0	166	199	33	5.8	275	0	0.0	10	29	0.3	0.12	0.41
33 CHEMICAL SLUDGE PUMPING-DILUTE	50.0	218	262	66	8.5	412	0	0.0	15	40	0.2	0.08	0.28
34 GRAVITY THICKENER	1.0	130	156	3	0.1	298	0	0.0	3	18	4.9	1.80	6.30
34 GRAVITY THICKENER	5.0	140	168	3	0.1	302	0	0.0	3	19	1.0	0.38	1.33
34 GRAVITY THICKENER	10.0	160	192	3	0.1	310	0	0.0	3	21	0.6	0.21	0.74
34 GRAVITY THICKENER	25.0	256	307	6	0.3	629	0	0.0	7	36	0.4	0.14	0.50
34 GRAVITY THICKENER	50.0	329	395	8	0.5	669	0	0.0	7	44	0.2	0.09	0.31
35 DECANTER CENTRIFUGE	1.0	301	361	38	1.5	729	0	0.0	10	44	12.1	4.40	15.40
35 DECANTER CENTRIFUGE	5.0	313	376	45	1.7	772	0	0.0	11	46	2.5	0.92	3.22
35 DECANTER CENTRIFUGE	10.0	358	430	71	2.6	936	0	0.0	14	55	1.5	0.55	1.93
35 DECANTER CENTRIFUGE	25.0	481	577	146	5.2	1383	0	0.0	23	77	0.8	0.31	1.08
35 DECANTER CENTRIFUGE	50.0	625	750	252	8.3	1906	0	0.0	35	106	0.6	0.21	0.74
36 MULTIPLE HEARTH RECALCINATION	1.0	PROCESS NOT INCLUDED FOR THIS PLANT CAPACITY											
36 MULTIPLE HEARTH RECALCINATION	5.0	1220	1464	301	5.6	2708	25903	0.0	119	257	14.1	5.14	17.99
36 MULTIPLE HEARTH RECALCINATION	10.0	1590	1908	421	7.9	4188	34334	0.0	165	345	9.5	3.45	12.08
36 MULTIPLE HEARTH RECALCINATION	25.0	2556	3067	688	13.9	7966	66490	0.0	314	604	6.6	2.42	8.46
36 MULTIPLE HEARTH RECALCINATION	50.0	3682	4418	1025	22.0	12539	138002	0.0	592	1009	5.5	2.02	7.06
37 SLUDGE HAULING	1.0	0	0	0	0.9	163	0	0.0	2	2	0.5	0.20	0.70
37 SLUDGE HAULING	5.0	0	0	0	1.0	198	0	0.0	3	3	0.2	0.06	0.21
37 SLUDGE HAULING	10.0	0	0	0	1.6	371	0	0.0	5	5	0.1	0.05	0.18
37 SLUDGE HAULING	25.0	0	0	0	3.4	903	0	0.0	12	12	0.1	0.05	0.17
37 SLUDGE HAULING	50.0	0	0	0	6.6	1824	0	0.0	25	25	0.1	0.05	0.18
TOTAL COST FOR COMPONENTS 24 THRU 37: LIME CLARIFICATION													
LIME CLARIFICATION	1.0	1527	1834	434	12.1	3862	13815	0.3	105	256	70.1	25.60	89.60
LIME CLARIFICATION	5.0	3540	4250	3187	21.4	7912	25903	1.5	279	627	34.4	12.54	43.89
LIME CLARIFICATION	10.0	5010	6013	6115	30.3	10931	34334	3.0	436	931	25.5	9.31	32.59
LIME CLARIFICATION	25.0	8454	10147	14818	53.4	18874	66490	7.6	915	1749	19.2	7.00	24.49
LIME CLARIFICATION	50.0	12397	14877	29218	83.4	28406	138002	11.4	1704	2926	16.0	5.85	20.48

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS* THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
THE FOLLOWING 7 PROCESSES ARE COST COMPONENTS OF MIXED MEDIA FILTRATION-AWT													
38 GRAVITY FILTRATION STRUCTURE	1.0	194	233	16	1.8	1929	0	0.0	22	44	12.1	4.40	15.40
38 GRAVITY FILTRATION STRUCTURE	5.0	499	599	44	5.4	2353	0	0.0	30	87	4.8	1.74	6.09
38 GRAVITY FILTRATION STRUCTURE	10.0	797	956	72	9.0	2837	0	0.0	40	130	3.6	1.30	4.55
38 GRAVITY FILTRATION STRUCTURE	25.0	1565	1878	147	18.7	4524	0	0.0	68	245	2.7	0.98	3.43
38 GRAVITY FILTRATION STRUCTURE	50.0	2420	2904	240	30.6	7741	0	0.0	115	389	2.1	0.78	2.72
39 FILTRA-HYDRAULIC SURFACE WASH	1.0	21	25	2	0.0	54	0	0.0	1	3	0.8	0.30	1.05
39 FILTRA-HYDRAULIC SURFACE WASH	5.0	38	46	10	0.0	115	0	0.0	1	5	0.3	0.10	0.35
39 FILTRA-HYDRAULIC SURFACE WASH	10.0	56	67	20	0.0	178	0	0.0	2	8	0.2	0.08	0.28
39 FILTRA-HYDRAULIC SURFACE WASH	25.0	97	116	49	0.0	248	0	0.0	4	15	0.2	0.06	0.21
39 FILTRA-HYDRAULIC SURFACE WASH	50.0	162	194	97	0.1	311	0	0.0	6	24	0.1	0.05	0.17
40 FILTRA-BACKWASH PUMPING SYSTEM	1.0	142	170	3	0.0	5	0	0.0	0	16	4.4	1.60	5.60
40 FILTRA-BACKWASH PUMPING SYSTEM	5.0	348	418	17	0.1	12	0	0.0	1	40	2.2	0.80	2.80
40 FILTRA-BACKWASH PUMPING SYSTEM	10.0	539	647	33	0.1	19	0	0.0	1	62	1.7	0.62	2.17
40 FILTRA-BACKWASH PUMPING SYSTEM	25.0	883	1060	83	0.2	29	0	0.0	3	103	1.1	0.41	1.44
40 FILTRA-BACKWASH PUMPING SYSTEM	50.0	1211	1453	166	0.4	43	0	0.0	6	143	0.8	0.29	1.00
41 MEDIA-MIXED MEDIA FILTRATION	1.0	12	14	0	0.0	0	0	0.0	0	1	0.3	0.10	0.35
41 MEDIA-MIXED MEDIA FILTRATION	5.0	34	41	0	0.0	0	0	0.0	0	4	0.2	0.08	0.28
41 MEDIA-MIXED MEDIA FILTRATION	10.0	56	67	0	0.0	0	0	0.0	0	6	0.2	0.06	0.21
41 MEDIA-MIXED MEDIA FILTRATION	25.0	119	143	0	0.0	0	0	0.0	0	13	0.1	0.05	0.18
41 MEDIA-MIXED MEDIA FILTRATION	50.0	208	250	0	0.0	0	0	0.0	0	24	0.1	0.05	0.17
42 SUPPLY PUMPING	1.0	30	36	45	0.3	520	0	0.0	7	10	2.7	1.00	3.50
42 SUPPLY PUMPING	5.0	47	56	226	0.9	623	0	0.0	14	19	1.0	0.38	1.33
42 SUPPLY PUMPING	10.0	69	83	451	1.6	747	0	0.0	23	31	0.8	0.31	1.09
42 SUPPLY PUMPING	25.0	132	158	1128	3.7	1096	0	0.0	49	64	0.7	0.26	0.90
42 SUPPLY PUMPING	50.0	234	281	2254	7.6	1618	0	0.0	91	118	0.6	0.24	0.83
43 POLYMER FEED SYSTEMS	1.0	44	53	23	0.2	198	0	0.3	4	9	2.5	0.90	3.15
43 POLYMER FEED SYSTEMS	5.0	46	55	23	0.2	198	0	1.5	9	14	0.8	0.28	0.98
43 POLYMER FEED SYSTEMS	10.0	51	61	23	0.3	199	0	3.0	15	21	0.6	0.21	0.74
43 POLYMER FEED SYSTEMS	25.0	67	80	23	0.3	201	0	7.6	33	41	0.4	0.16	0.57
43 POLYMER FEED SYSTEMS	50.0	100	120	46	0.6	403	0	11.4	52	63	0.3	0.13	0.44
44 ALUM FEED SYSTEM	1.0	24	29	9	0.2	284	0	15.3	4	7	1.9	0.70	2.45
44 ALUM FEED SYSTEM	5.0	41	49	10	0.2	293	0	76.2	9	14	0.8	0.28	0.98
44 ALUM FEED SYSTEM	10.0	60	72	11	0.2	304	0	152.4	15	22	0.6	0.22	0.77
44 ALUM FEED SYSTEM	25.0	106	127	15	0.2	341	0	381.1	33	45	0.5	0.18	0.63
44 ALUM FEED SYSTEM	50.0	149	179	21	0.2	405	0	762.1	62	79	0.4	0.16	0.55

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      COMPONENT                    AVE   CONSTN  CAPITAL  ELEC    MAINT                 FUEL              TOTAL    *TOTAL ANNUAL COST FACTORS*
         OR                        FLOW   COST    COST    THOU    MAT'L    LABOR    MIL        CHEM    O&M/YR   THOU  CTS/     $ PER    $ PER
       SYSTEM                      MGD   THOU $  THOU $  KWH/YR   K$/YR    HR/YR   BTU/YR      TN/YR   THOU $   $     K GAL   CAPITA     HOME

                  TOTAL COST FOR COMPONENTS  38 THRU  44:   MIXED MEDIA FILTRATION-AWT

MIXED MEDIA FILTRATION-AWT         1.0     534     640      98     2.6     2990         0     15.6       38     90   24.7     9.00    31.50
MIXED MEDIA FILTRATION-AWT         5.0    1208    1450     330     6.8     3594         0     77.7       64    183   10.0     3.66    12.81
MIXED MEDIA FILTRATION-AWT        10.0    1869    2244     610    11.2     4284         0    155.5       96    280    7.7     2.80     9.80
MIXED MEDIA FILTRATION-AWT        25.0    3410    4094    1445    23.2     6439         0    388.7      190    526    5.8     2.10     7.36
MIXED MEDIA FILTRATION-AWT        50.0    5155    6185    2824    39.6    10521         0    773.5      332    840    4.6     1.68     5.88

               THE FOLLOWING  3 PROCESSES ARE COST COMPONENTS OF ACTIVATED CARBON ADSORPTION

 45 UPFLOW GRAN CARBON CONTACTORS  1.0     410     492     123     1.5     2001         0      0.0       25     71   19.5     7.10    24.85
 45 UPFLOW GRAN CARBON CONTACTORS  5.0    1653    1984     222     4.3     2640         0      0.0       37    224   12.3     4.48    15.68
 45 UPFLOW GRAN CARBON CONTACTORS 10.0    3203    3844     348     7.7     3406         0      0.0       52    415   11.4     4.15    14.53
 45 UPFLOW GRAN CARBON CONTACTORS 25.0    7151    8581     746    17.6     5501         0      0.0       95    905    9.9     3.62    12.67
 45 UPFLOW GRAN CARBON CONTACTORS 50.0   13393   16072    1470    33.2     8479         0      0.0      162   1679    9.2     3.36    11.75

 46 GRANULAR ACTIVATED CARBON      1.0      73      88       0     0.0        0         0      0.0        0      8    2.2     0.80     2.80
 46 GRANULAR ACTIVATED CARBON      5.0     298     358       0     0.0        0         0      0.0        0     34    1.9     0.68     2.38
 46 GRANULAR ACTIVATED CARBON     10.0     592     710       0     0.0        0         0      0.0        0     67    1.8     0.67     2.34
 46 GRANULAR ACTIVATED CARBON     25.0    1396    1675       0     0.0        0         0      0.0        0    158    1.7     0.63     2.21
 46 GRANULAR ACTIVATED CARBON     50.0    2704    3245       0     0.0        0         0      0.0        0    306    1.7     0.61     2.14

 47 GRAN ACT CARBON REGENERATION   1.0     577     692     182     1.8      410      1508      4.6       22     87   23.8     8.70    30.45
 47 GRAN ACT CARBON REGENERATION   5.0     895    1074     261     3.9     1380      6400     22.8       74    175    9.6     3.50    12.25
 47 GRAN ACT CARBON REGENERATION  10.0    1262    1514     297     5.1     2585     11549     45.6      134    277    7.6     2.77     9.70
 47 GRAN ACT CARBON REGENERATION  25.0    2015    2418     401     7.8     5560     26245    114.1      302    530    5.8     2.12     7.42
 47 GRAN ACT CARBON REGENERATION  50.0    2581    3097     560    10.0     8880     48933    228.1      559    851    4.7     1.70     5.96

                  TOTAL COST FOR COMPONENTS  45 THRU  47:   ACTIVATED CARBON ADSORPTION

ACTIVATED CARBON ADSORPTION        1.0    1217    1461     305     3.3     2411      1508      4.6       47    166   45.5    16.60    58.10
ACTIVATED CARBON ADSORPTION        5.0    3271    3927     483     8.2     4020      6400     22.8      111    433   23.7     8.66    30.31
ACTIVATED CARBON ADSORPTION       10.0    5814    6977     645    12.8     5991     11549     45.6      186    759   20.8     7.59    26.57
ACTIVATED CARBON ADSORPTION       25.0   12145   14574    1147    25.4    11061     26245    114.1      397   1593   17.5     6.37    22.30
ACTIVATED CARBON ADSORPTION       50.0   21478   25774    2030    43.2    17359     48933    228.1      721   2836   15.5     5.67    19.85

 48 STANDBY POWER, SEC TRT         1.0     150     180       0     0.1        8      2738      0.0        8     25    6.8     2.50     8.75
 48 STANDBY POWER, SEC TRT         5.0     175     210       0     0.1       10      3427      0.0       10     30    1.6     0.60     2.10
 48 STANDBY POWER, SEC TRT        10.0     300     360       0     0.1       20      6762      0.0       21     55    1.5     0.55     1.93
 48 STANDBY POWER, SEC TRT        25.0     436     523       0     0.2       30     10339      0.0       32     81    0.9     0.32     1.13
 48 STANDBY POWER, SEC TRT        50.0    1337    1604       0     0.6       96     32662      0.0      100    251    1.4     0.50     1.76
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COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS*			
										THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
49 STANDBY POWER, AWT	1.0	150	180	0	0.1	8	2738	0.0	8	25	6.8	2.50	8.75
49 STANDBY POWER, AWT	5.0	361	433	0	0.2	24	8370	0.0	26	67	3.7	1.34	4.69
49 STANDBY POWER, AUT	10.0	654	785	0	0.3	46	15910	0.0	48	122	3.3	1.22	4.27
49 STANDBY POWER, AWT	25.0	1309	1571	0	0.6	94	31971	0.0	97	245	2.7	0.98	3.43
49 STANDBY POWER, AWT	50.0	3109	3731	0	1.4	220	75070	0.0	229	581	3.2	1.16	4.07
50 EARTHEN STORAGE, 1 DAY	1.0	35	42	0	0.0	0	0	0.0	0	4	1.1	0.40	1.40
50 EARTHEN STORAGE, 1 DAY	5.0	94	113	0	0.0	0	0	0.0	0	11	0.6	0.22	0.77
50 EARTHEN STORAGE, 1 DAY	10.0	164	197	0	0.0	0	0	0.0	0	19	0.5	0.19	0.66
50 EARTHEN STORAGE, 1 DAY	25.0	348	418	0	0.0	0	0	0.0	0	39	0.4	0.16	0.55
50 EARTHEN STORAGE, 1 DAY	50.0	581	697	0	0.0	0	0	0.0	0	66	0.4	0.13	0.46
51 EARTHEN STORAGE, 2 DAYS	1.0	50	60	0	0.0	0	0	0.0	0	6	1.6	0.60	2.10
51 EARTHEN STORAGE, 2 DAYS	5.0	164	197	0	0.0	0	0	0.0	0	19	1.0	0.38	1.33
51 EARTHEN STORAGE, 2 DAYS	10.0	291	349	0	0.0	0	0	0.0	0	33	0.9	0.33	1.16
51 EARTHEN STORAGE, 2 DAYS	25.0	581	697	0	0.0	0	0	0.0	0	66	0.7	0.26	0.92
51 EARTHEN STORAGE, 2 DAYS	50.0	896	1075	0	0.0	0	0	0.0	0	101	0.6	0.20	0.71
52 EARTHEN STORAGE, 4 DAYS	1.0	80	96	0	0.0	0	0	0.0	0	9	2.5	0.90	3.15
52 EARTHEN STORAGE, 4 DAYS	5.0	291	349	0	0.0	0	0	0.0	0	33	1.8	0.66	2.31
52 EARTHEN STORAGE, 4 DAYS	10.0	497	596	0	0.0	0	0	0.0	0	56	1.5	0.56	1.96
52 EARTHEN STORAGE, 4 DAYS	25.0	896	1075	0	0.0	0	0	0.0	0	101	1.1	0.40	1.41
52 EARTHEN STORAGE, 4 DAYS	50.0	1858	2230	0	0.0	0	0	0.0	0	210	1.2	0.42	1.47
53 EARTHEN STORAGE, 8 DAYS	1.0	137	164	0	0.0	0	0	0.0	0	15	4.1	1.50	5.25
53 EARTHEN STORAGE, 8 DAYS	5.0	497	596	0	0.0	0	0	0.0	0	56	3.1	1.12	3.92
53 EARTHEN STORAGE, 8 DAYS	10.0	782	938	0	0.0	0	0	0.0	0	89	2.4	0.89	3.12
53 EARTHEN STORAGE, 8 DAYS	25.0	1858	2230	0	0.0	0	0	0.0	0	210	2.3	0.84	2.94
53 EARTHEN STORAGE, 8 DAYS	50.0		PROCESS NOT INCLUDED FOR THIS PLANT CAPACITY										
54 EARTHEN STORAGE, 10 DAYS	1.0	164	197	0	0.0	0	0	0.0	0	19	5.2	1.90	6.65
54 EARTHEN STORAGE, 10 DAYS	5.0	581	697	0	0.0	0	0	0.0	0	66	3.6	1.32	4.62
54 EARTHEN STORAGE, 10 DAYS	10.0	896	1075	0	0.0	0	0	0.0	0	101	2.8	1.01	3.54
54 EARTHEN STORAGE, 10 DAYS	25.0		PROCESS NOT INCLUDED FOR THIS PLANT CAPACITY										
54 EARTHEN STORAGE, 10 DAYS	50.0		PROCESS NOT INCLUDED FOR THIS PLANT CAPACITY										
55 EARTHEN STORAGE, 15 DAYS	1.0	230	276	0	0.0	0	0	0.0	0	26	7.1	2.60	9.10
55 EARTHEN STORAGE, 15 DAYS	5.0	753	904	0	0.0	0	0	0.0	0	85	4.7	1.70	5.95
55 EARTHEN STORAGE, 15 DAYS	10.0	1232	1478	0	0.0	0	0	0.0	0	140	3.8	1.40	4.90
55 EARTHEN STORAGE, 15 DAYS	25.0		PROCESS NOT INCLUDED FOR THIS PLANT CAPACITY										
55 EARTHEN STORAGE, 15 DAYS	50.0		PROCESS NOT INCLUDED FOR THIS PLANT CAPACITY										

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     COMPONENT                 AVE   CONSTN  CAPITAL   ELEC   MAINT            FUEL             TOTAL   *TOTAL ANNUAL COST FACTORS*
        OR                     FLOW   COST    COST     THOU   MAT'L   LABOR    MIL      CHEM    O&M/YR   THOU   CTS/   $ PER    $ PER
      SYSTEM                   MGD   THOU $  THOU $   KWH/YR  K$/YR   HR/YR   BTU/YR    TN/YR   THOU $    $     K GAL  CAPITA    HOME

56 EARTHEN STORAGE, 20 DAYS     1.0     291     349       0    0.0       0        0       0.0      0       33     9.0    3.30    11.55
56 EARTHEN STORAGE, 20 DAYS     5.0     896    1075       0    0.0       0        0       0.0      0      101     5.5    2.02     7.07
56 EARTHEN STORAGE, 20 DAYS    10.0    1858    2230       0    0.0       0        0       0.0      0      210     5.8    2.10     7.35
56 EARTHEN STORAGE, 20 DAYS    25.0           PROCESS NOT INCLUDED FOR THIS PLANT CAPACITY
56 EARTHEN STORAGE, 20 DAYS    50.0           PROCESS NOT INCLUDED FOR THIS PLANT CAPACITY

57 EARTHEN STORAGE, 30 DAYS     1.0     401     481       0    0.0       0        0       0.0      0       45    12.3    4.50    15.75
57 EARTHEN STORAGE, 30 DAYS     5.0    1232    1478       0    0.0       0        0       0.0      0      140     7.7    2.80     9.80
57 EARTHEN STORAGE, 30 DAYS    10.0           PROCESS NOT INCLUDED FOR THIS PLANT CAPACITY
57 EARTHEN STORAGE, 30 DAYS    25.0           PROCESS NOT INCLUDED FOR THIS PLANT CAPACITY
57 EARTHEN STORAGE, 30 DAYS    50.0           PROCESS NOT INCLUDED FOR THIS PLANT CAPACITY


        ***** TREATMENT SYSTEM COST SUMMARIES INCLUDING YARD PIPING AT 15 PERCENT OF CONSTRUCTION COST *****

SECONDARY TREATMENT-ACT SLUDGE  1.0    2343    2812     759   20.2   10318     4854      15.3    164      394   107.9   39.40   137.90
SECONDARY TREATMENT-ACT SLUDGE  5.0    6861    8232    4004   44.7   21917    14007      76.3    442     1118    61.3   22.36    78.26
SECONDARY TREATMENT-ACT SLUDGE 10.0   10886   13064    6826   72.6   35783    27922     152.4    752     1823    49.9   18.23    63.81
SECONDARY TREATMENT-ACT SLUDGE 25.0   20701   24841   16204  152.9   76430    63239     381.1   1680     3719    40.8   14.88    52.07
SECONDARY TREATMENT-ACT SLUDGE 50.0   34162   40995   29994  267.1  110387   138462     761.9   2853     6218    34.1   12.44    43.53

SEC TRT + STORAGE, 1 DAY        1.0    2383    2860     759   20.2   10318     4854      15.3    164      398   109.0   39.80   139.30
SEC TRT + STORAGE, 1 DAY        5.0    6969    8361    4004   44.7   21917    14007      76.3    442     1129    61.9   22.58    79.03
SEC TRT + STORAGE, 1 DAY       10.0   11074   13290    6826   72.6   35783    27922     152.4    752     1842    50.5   18.42    64.47
SEC TRT + STORAGE, 1 DAY       25.0   21101   25321   16204  152.9   76430    63239     381.1   1680     3758    41.2   15.03    52.61
SEC TRT + STORAGE, 1 DAY       50.0   34830   41796   29994  267.1  110387   138462     761.9   2853     6284    34.4   12.57    43.99

ADVANCED WASTEWATER TREATMENT   1.0    5621    6747    1596   38.1   19581    20177      35.8    354      906   248.2   90.60   317.10
ADVANCED WASTEWATER TREATMENT   5.0   15094   18115    8004   81.2   37457    51253     178.4    912     2398   131.4   47.96   167.86
ADVANCED WASTEWATER TREATMENT  10.0   23986   28786   14196  127.1   57015    82953     356.5   1497     3860   105.8   38.60   135.10
ADVANCED WASTEWATER TREATMENT  25.0   45714   54861   33614  255.4  112868   177606     891.4   3247     7751    84.9   31.00   108.51
ADVANCED WASTEWATER TREATMENT  50.0   75230   90277   64066  434.1  166797   367805    1775.0   5739    13150    72.1   26.30    92.05

AWT+ STORAGE, 1 DAY             1.0    5661    6795    1596   38.1   19581    20177      35.8    354      910   249.3   91.00   318.50
AWT+ STORAGE, 1 DAY             5.0   15202   18244    8004   81.2   37457    51253     178.4    912     2409   132.0   48.18   168.63
AWT+ STORAGE, 1 DAY            10.0   24174   29012   14196  127.1   57015    82953     356.5   1497     3879   106.3   38.79   135.77
AWT+ STORAGE, 1 DAY            25.0   46114   55341   33614  255.4  112868   177606     891.4   3247     7790    85.4   31.16   109.06
AWT+ STORAGE, 1 DAY            50.0   75898   91078   64066  434.1  166797   367805    1775.0   5739    13216    72.4   26.43    92.51
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DESIGN CRITERIA AND UNIT PROCESS SIZES

PROCESS OR COMPONENT	DESIGN FLOW,MGD				
AVERAGE:	1.0	5.0	10.0	25.0	50.0
PEAK:	2.0	10.0	20.0	45.0	80.0
1 RAW WASTEWATER PUMPING, FIRM CAPACITY, MGD	2.0	10.0	20.0	45.0	80.0
INCLUDES SCREENING AND STANDBY PUMP EQUAL TO LARGEST UNIT					
2 AERATED GRIT CHAMBER,VOLUME,CU FT (INCL STNBY)	928.0	4642.0	6963.0	15668.0	27852.0
DETENTION TIME = 2.5 MINUTES AT PEAK DESIGN FLOW					
3 CIRCULAR PRIMARY CLARIFIER, SURFACE AREA/UNIT, SQ FT	625.0	3125.0	3125.0	7815.0	15625.0
NUMBER OF UNITS	3	3	5	5	5
OVERFLOW RATE = 800 GAL/DAY/SQ FT (INCL STNBY UNIT)					
4 AERATION BASIN,VOLUME,CU FT (INCL STNBY CAPACITY)	66900.0	334500.0	557500.0	1301200.0	2602410.0
HYDRAULIC DETENTION TIME = 8 HRS					
5 MECHANICAL AERATION EQUIPMENT, INSTALLED HP (INCL STNBY)	120.0	600.0	1000.0	2500.0	4670.0
MAXIMUM OXYGEN UPTAKE RATE = 70 MG/L/HR					
6 CIRCULAR SECONDARY CLARIFIER, SURFACE AREA/UNIT, SQ FT	833.0	4167.0	4167.0	10419.0	13891.0
NUMBER OF UNITS	3	3	5	5	7
OVERFLOW RATE = 600 GAL/DAY/SQ FT (INCL STNBY)					
7 CHLORINE FEED SYSTEMS, FEED CAPACITY, LB/DAY	167.0	835.0	1670.0	3758.0	6680.0
SIZED FOR 10 MG/L DOSE AT PEAK DESIGN FLOW					
8 CHLORINE CONTACT BASIN, VOLUME, CU FT	5570.0	27852.0	55704.0	125334.0	222816.0
DETENTION TIME = 30 MINUTES AT PEAK DESIGN FLOW					
9 RETURN ACTIVATED SLUDGE PUMPING, FIRM CAPACITY, MGD	1.0	5.0	10.0	22.5	40.0
CAPACITY = 50 PER CENT OF PEAK DESIGN FLOW					
10 WASTE SLUDGE PUMPING, FIRM PUMPING CAPACITY, GPM	66.0	330.0	660.0	1650.0	3300.0
SIZED FOR INTERMITTENT OPERATION OF 10 MIN/HR AT AVE FLOW					
11 GRAVITY THICKENER,SURFACE AREA/UNIT,SQ FT (INCL STNBY)	115.0	163.0	325.0	813.0	1625.0
NUMBER OF UNITS	2	3	3	3	3
SOLIDS LOADING = 20 LB/SQ FT/DAY FOR PRIMARY SLUDGE					
12 FLOTATION THICKENER,TOTAL SURFACE AREA,SQ FT (INCL STNBY)	0.0	500.0	1000.0	1662.0	3000.0
SOLIDS LOADING = 20 LB/SQ FT/DAY FOR WASTE ACTIVATED SLUDGE					
13 ANAEROBIC DIGESTER,VOLUME,CU FT,INCLUDES PRIMARY & SECONDARY	29775.0	148875.0	248125.0	620310.0	1158250.0
TOTAL DETENTION TIME = 30 DAYS (INCL STNBY UNIT)					
14 SAND DRYING BEDS, SURFACE AREA, SQ FT	22000.0	110000.0	220000.0	550000.0	1100000.0
SOLIDS LOADING = 25 LB/SQ FT/YEAR					
15 SLUDGE HAULING, ANNUAL VOLUME, CU YD	730.0	3650.0	7300.0	18250.0	36500.0
SLUDGE DRIED TO 45% SOLIDS ON SAND BEDS					
16 YARD MAINTENANCE, AREA OF PLANT SITE, SQ FT	271800.0	322000.0	435600.0	740500.0	1002000.0
AREA REQUIREMENTS ADAPTED FROM BLACK & VEATCH REPORT, 1971					

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        DESIGN CRITERIA AND UNIT PROCESS SIZES

PROCESS OR COMPONENT                        DESIGN FLOW,MGD
                                                AVERAGE:      1.0       5.0      10.0      25.0      50.0
                                                PEAK:         2.0      10.0      20.0      45.0      80.0


 17 GRAVITY FILTRATION STRUCTURE, TOTAL FILTER AREA, SQ FT  464.0    1540.0    2890.0    6940.0   13500.0
    (INCL STNBY UNITS)  FILTRATION RATE = 3 GPM/SQ FT, SEC EFFL

 18 FILTRA-HYDRAULIC SURFACE WASH,INDIVIDUAL FILTER AREA,SQ FT  116.0  193.0  289.0    578.0     964.0
    NUMBER OF UNITS                                            4         8        10        12        14
    (INCL STNBY UNITS)  FILTRATION RATE = 3 GPM/SQ FT, SEC EFFL

 19 FILTRA-BACKWASH PUMPING SYSTEM, FIRM PUMPING CAPACITY, GPM  2090.0  3470.0  5200.0  10400.0  17400.0
    NUMBER OF UNITS                                            4         8        10        12        14
    (INCL STNBY UNITS)  SEC EFFL, BACKWASH CAPACITY=18 GPM/SQ FT

 20 MEDIA-MIXED MEDIA FILTRATION, TOTAL FILTER AREA, SQ FT  464.0    1540.0    2890.0    6940.0   13500.0
    (INCL STNBY UNITS)  SEC EFFL, FILTRATION RATE = 3 GPM/SQ FT

 21 SUPPLY PUMPING, PUMPING RATE, MGD                          1.0       5.0      10.0      25.0      50.0
    GRAVITY FILTER OR AWT UPFLOW CARBON CONTACTOR SUPPLY

 22 POLYMER FEED SYSTEMS, FEED CAPACITY/UNIT,LBS/DAY           8.3      42.0      83.0     208.0     208.0
    NUMBER OF UNITS                                            2         2         2         2         3
    (INCL STNBY)   COAGULANT AID,1 MG/L CAPACITY,0.1 MG/L AVG

 23 ALUM FEED SYSTEM-DRY ALUM, CAPACITY, LBS/HR               14.0      70.0     140.0     348.0     696.0
    (INCL STNBY) FILTER AID, 20 MG/L CAPACITY, 10 MG/L AVG

 24 LIME FEED SYSTEM, CAO FEED CAPACITY, LBS/HR              208.0    1040.0    2080.0    4690.0    8340.0
    SIZED FOR 300 MG/L DOSE AT PEAK FLOW

 25 POLYMER FEED SYSTEM, FEED CAPACITY/UNIT, LBS/DAY           8.3      42.0      83.0     208.0     208.0
    NUMBER OF UNITS                                            2         2         2         2         3
    1 MG/L CAPACITY, 0.1 MG/L AVG FEED RATE (INCL STNBY)

 26 RAPID MIX BASIN,VOLUME,CU FT (INCL STNBY UNIT)            93.0     464.0     928.0    2320.0    4640.0
    NUMBER OF UNITS                                            2         2         2         2         2
    DETENTION TIME = 60 SEC AT AVG FLOW

 27 FLOCCULATION BASIN,TOTAL VOLUME,CU FT (INCL STNBY)      5560.0   20850.0   41700.0  104250.0  208500.0
    HORIZONTAL PADDLE, G=80, DETENTION TIME=30 MIN AT AVG FLOW

 28 CIRCULAR CLARIFIER,SURFACE AREA/UNIT,SQ FT (INCL STNBY)  526.0    2630.0    5260.0    6580.0   13200.0
    NUMBER OF UNITS                                            3         3         3         5         5
    OVERFLOW RATE = 950 GAL/DAY/SQ FT

 29 RECARBONATION BASIN,VOLUME/UNIT,CU FT (INCL STNBY)       770.0    1740.0    3480.0    8700.0    8700.0
    NUMBER OF UNITS                                            4         6         6         6        10
    15 MIN DETENTION AT AVG FLOW

 30 RECARBONATION-SUBMERGED BURNERS,CAPACITY/UNIT,LBS CO2/DAY  2190.0   0.0       0.0       0.0       0.0
    NUMBER OF UNITS                                            4         0         0         0         0
    (INCL STNBY UNITS)    MAXIMUM FEED RATE = 525 MG/L CO2
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              DESIGN CRITERIA AND UNIT PROCESS SIZES

    PROCESS OR COMPONENT                                    DESIGN FLOW,MGD
                                                               AVERAGE:         1.0        5.0       10.0       25.0       50.0
                                                               PEAK:            2.0       10.0       20.0       45.0       80.0

     31 RECARBONATION-STACK GAS,CAPACITY,LBS CO2/DAY (INCL STNBY)               0.0    43800.0    87600.0   147000.0   263000.0
        AVG FEED RATE = 350 MG/L, MAX RATE = 525 MG/L

     32 RECTANGULAR CLARIFIER,SURFACE AREA/UNIT,SQ FT (INCL STNBY)            333.0      833.0     1670.0     4170.0     4170.0
        NUMBER OF UNITS                                                           2          3          3          3          5
        RECARB-INTERMEDIATE SETTLING,OVERFLOW RATE=3000 GPD/SQ FT

     33 CHEMICAL SLUDGE PUMPING, FIRM PUMPING CAPACITY, GPM                    83.0      416.0      833.0     2080.0     4160.0
        SIZED FOR 600 MG/L DOSE AND 0.5% SOLIDS,AVG=300 MG/L @ 1.0%

     34 GRAVITY THICKENER,SURFACE AREA/UNIT,SQ FT (INCL STNBY)                 78.0      150.0      300.0      375.0      750.0
        NUMBER OF UNITS                                                           2          2          2          3          3
        LIME SLUDGE @ 1% SOLIDS, OVERFLOW RATE=1000 GPD/SQ FT

     35 DECANTER CENTRIFUGE,FEED CAPACITY,GPM (INCL STNBY UNIT)                10.0       13.0       25.0       63.0      125.0
        NUMBER OF UNITS                                                           2          2          2          2          2
        LIME SLUDGE, 8% SOLIDS AS INFLUENT

     36 MULTIPLE HEARTH RECALCINATION, EFFECTIVE HEARTH AREA,SQ FT              0.0      149.0      297.0      746.0     1490.0
        WET FEED OF 7.0 LB/SQ FT/HR AT 50% SOLIDS

     37 SLUDGE HAULING, ANNUAL VOLUME, CU  YD                                1320.0     1650.0     3300.0     8250.0    16500.0
        LIME SLUDGE AT 50% SOLIDS, 25% WASTED FOR PLANTS OVER 1 MGD

     38 GRAVITY FILTRATION STRUCTURE, TOTAL FILTER AREA, SQ FT                278.0     1040.0     1850.0     4340.0     8330.0
        (INCL STNBY UNITS)  FILTRATION RATE=5 GPM/SQ FT, WATER & AWT

     39 FILTRA-HYDRAULIC SURFACE WASH, INDIVIDUAL FILTER AREA, SQ FT           69.0      174.0      231.0      434.0      694.0
        NUMBER OF UNITS                                                           4          6          8         10         12
        (INCL STNBY UNITS) FILTRATION RATE=5 GPM/SQ FT, WATER & AWT

     40 FILTRA-BACKWASH PUMPING SYSTEM, FIRM PUMPING CAPACITY, GPM           1240.0     3130.0     4160.0     7810.0    12500.0
        NUMBER OF UNITS                                                           4          6          8         10         12
        (INCL STNBY UNITS) WATER&AWT, BACKWASH CAPACITY=18 GPM/SQ FT

     41 MEDIA-MIXED MEDIA FILTRATION, TOTAL FILTER AREA, SQ FT                278.0     1040.0     1850.0     4340.0     8330.0
        (INCL STANBY UNITS) WATER & AWT, FILTRATION RATE=5 GPM/SQ FT

     42 SUPPLY PUMPING,PUMPING RATE, MGD                                        1.0        5.0       10.0       25.0       50.0
        GRAVITY FILTER OR AWT UPFLOW CARBON CONTACTOR SUPPLY

     43 POLYMER FEED SYSTEMS, FEED CAPACITY/UNIT, LBS/DAY                       8.3       42.0       83.0      208.0      208.0
        NUMBER OF UNITS                                                           2          2          2          2          3
        (INCL STNBY)   COAGULANT AID,1 MG/L CAPACITY,0.1 MG/L AVG

     44 ALUM FEED SYSTEM-DRY ALUM,CAPACITY,LBS/HR (INCL STNBY)                 14.0       70.0      140.0      348.0      696.0
        MIXED MEDIA FILTER AID, 20 MG/L CAPACITY, 10 MG/L AVG

     45 UPFLOW GRAN CARBON CONTACTORS, AVG FLOW,MGD (INCL STNBY)                1.5        6.3       12.5       30.0       60.0
        CONTACT TIME=30 MIN, HYDRAULIC LOADING = 5 GPM/SQ FT
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DESIGN CRITERIA AND UNIT PROCESS SIZES

PROCESS OR COMPONENT	DESIGN FLOW,MGD				
AVERAGE:	1.0	5.0	10.0	25.0	50.0
PEAK:	2.0	10.0	20.0	45.0	80.0
46 GRANULAR ACTIVATED CARBON, TOTAL WEIGHT, LBS CONTACT TIME= 30 MIN, CARBON WEIGHT = 30 LB/CU FT	125400.0	522500.0	1045000.0	2508000.0	5016000.0
47 GRANULAR CARBON REGENERATION, HEARTH AREA, SQ FT 40% DOWNTIME,40 LB/SQ FT/DAY; REMOVAL=0.5 LB COD/LB CARBON	27.0	104.0	208.0	521.0	1040.0
48 STANDBY POWER,RATED CAPACITY,KILOWATTS SECONDARY TREATMENT,SIZED FOR AVG POWER USE	62.0	313.0	618.0	945.0	2983.0
49 STANDBY POWER,RATED CAPACITY,KILOWATTS ADVANCED WASTEWATER TREATMENT,SIZED FOR AVG POWER USE	158.0	765.0	1454.0	2920.0	6841.0
50 EARTHEN STORAGE, 1 DAY, STORAGE CAPACITY, MGD INCLUDES CONCRETE SLOPE PAVING OR MATERIAL LINERS	1.0	5.0	10.0	25.0	50.0
51 EARTHEN STORAGE, 2 DAYS, STORAGE CAPACITY, MGD INCLUDES CONCRETE SLOPE PAVING OR MATERIAL LINERS	2.0	10.0	20.0	50.0	100.0
52 EARTHEN STORAGE, 4 DAYS, STORAGE CAPACITY, MGD INCLUDES CONCRETE SLOPE PAVING OR MATERIAL LINERS	4.0	20.0	40.0	100.0	200.0
53 EARTHEN STORAGE, 8 DAYS, STORAGE CAPACITY, MGD INCLUDES CONCRETE SLOPE PAVING OR MATERIAL LINERS	8.0	40.0	80.0	200.0	0.0
54 EARTHEN STORAGE, 10 DAYS, STORAGE CAPACITY, MGD INCLUDES CONCRETE SLOPE PAVING OR MATERIAL LINERS	10.0	50.0	100.0	0.0	0.0
55 EARTHEN STORAGE, 15 DAYS, STORAGE CAPACITY, MGD INCLUDES CONCRETE SLOPE PAVING OR MATERIAL LINERS	15.0	75.0	150.0	0.0	0.0
56 EARTHEN STORAGE, 20 DAYS, STORAGE CAPACITY, MGD INCLUDES CONCRETE SLOPE PAVING OR MATERIAL LINERS	20.0	100.0	200.0	0.0	0.0
57 EARTHEN STORAGE, 30 DAYS, STORAGE CAPACITY, MGD INCLUDES CONCRETE SLOPE PAVING OR MATERIAL LINERS	30.0	150.0	0.0	0.0	0.0

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COST INFORMATION:

 COSTS PRESENTED AS DOLLARS ARE CURRENT AS OF JANUARY 1977

 CAPITAL COST FACTORS:  INTEREST RATE(%)    =7
                        NUMBER OF YEARS     =20
                        ENGINEERING(%)      =10   (PER CENT OF CONSTRUCTION COST)
                        LEGAL,FISCAL(%)     =3    (PER CENT OF CONSTRUCTION COST)
                        INT DURING CONST(%)=7     (PER CENT OF CONSTRUCTION COST)
                        YARD PIPING FACTOR =15    (PER CENT OF CONSTRUCTION COST)

 PER CAPITA COSTS:      GAL/PERSON/DAY      =100
                        PEOPLE/HOME         =3.5

 UNIT COST FACTORS:     ELECTRICITY,$/KWH   =0.03
                        LABOR,$/HR          =10
                        FUEL,$/MIL BTU      =3

 CHEMICAL COSTS:        LIME,$/TON          =52
                        ALUM,$/TON          =75
                        CHLORINE,$/TON      =220
                        POLYMER,$/LB        =2

 CONSTN COST INDEXES:   EXCAVATION          =220.6  (ENR SKILLED LABOR)
                        MANUFACTURED EQUIP  =195.7  (BLS #114)
                        CONCRETE            =193.1  (BLS #132)
                        STEEL               =221.3  (BLS #101.3)
                        LABOR               =220.6  (ENR SKILLED LABOR)
                        PIPES & VALVES      =209.4  (BLS #114.901)
                        HOUSING             =30     (ACTUAL BLDG COST,$/SQ FT)
                        WHOLESALE PRICE     =188.0  (BLS ALL COMMODITIES)

 EPA CONSTN INDEXES:    SCCT(5 MGD PLANT)  =121     (NATIONAL INDEX VALUE)
                        LCAT(50 MGD PLANT) =132     (NATIONAL INDEX VALUE)
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COST SUMMARY

WATER TREATMENT SYSTEMS - INCREASED RELIABILITY

CONVENTIONAL WATER TREATMENT

UPGRADED WATER TREATMENT

UPGRADED TREATMENT AND REVERSE OSMOSIS

CONCRETE STORAGE BASIN

THE FOLLOWING 12 PROCESSES ARE COST COMPONENTS OF CLARIFICATION AND CHLORINATION

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS* THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
1 RAW WATER PUMPING	1.0	148	178	70	0.6	1012	0	0.0	13	30	8.2	3.00	10.50
1 RAW WATER PUMPING	5.0	411	493	269	1.4	1087	0	0.0	20	67	3.7	1.34	4.69
1 RAW WATER PUMPING	10.0	724	869	516	2.6	1195	0	0.0	30	112	3.1	1.12	3.92
1 RAW WATER PUMPING	25.0	1571	1885	1231	7.0	1609	0	0.0	60	238	2.6	0.95	3.33
1 RAW WATER PUMPING	50.0	2784	3341	2347	13.0	2498	0	0.0	108	423	2.3	0.85	2.96
2 RAPID MIX	1.0	21	25	32	0.2	470	0	0.0	6	8	2.2	0.80	2.80
2 RAPID MIX	5.0	44	53	157	0.5	468	0	0.0	10	15	0.8	0.30	1.05
2 RAPID MIX	10.0	73	88	315	0.8	469	0	0.0	15	23	0.6	0.23	0.80
2 RAPID MIX	25.0	160	192	787	1.8	499	0	0.0	30	48	0.5	0.19	0.67
2 RAPID MIX	50.0	300	360	1574	3.3	617	0	0.0	57	91	0.5	0.18	0.64
3 ALUM FEED SYSTEM	1.0	33	40	9	0.2	290	0	61.3	8	12	3.3	1.20	4.20
3 ALUM FEED SYSTEM	5.0	77	92	14	0.2	329	0	306.6	27	36	2.0	0.72	2.52
3 ALUM FEED SYSTEM	10.0	117	140	19	0.2	378	0	608.8	50	63	1.7	0.63	2.21
3 ALUM FEED SYSTEM	25.0	157	188	32	0.2	548	0	1524.2	121	139	1.5	0.56	1.95
3 ALUM FEED SYSTEM	50.0	74	89	50	0.3	884	0	3044.1	239	247	1.4	0.49	1.73
4 POLYMER FEED SYSTEMS	1.0	44	53	23	0.2	198	0	0.3	4	9	2.5	0.90	3.15
4 POLYMER FEED SYSTEMS	5.0	46	55	23	0.2	198	0	1.5	9	14	0.8	0.28	0.98
4 POLYMER FEED SYSTEMS	10.0	51	61	23	0.3	199	0	3.0	15	21	0.6	0.21	0.74
4 POLYMER FEED SYSTEMS	25.0	67	80	23	0.3	201	0	7.6	33	41	0.4	0.16	0.57
4 POLYMER FEED SYSTEMS	50.0	100	120	46	0.6	403	0	11.4	52	63	0.3	0.13	0.44
5 FLOCCULATION	1.0	59	71	19	0.6	120	0	0.0	2	9	2.5	0.90	3.15
5 FLOCCULATION	5.0	151	181	70	1.4	191	0	0.0	5	22	1.2	0.44	1.54
5 FLOCCULATION	10.0	250	300	140	2.4	260	0	0.0	9	37	1.0	0.37	1.30
5 FLOCCULATION	25.0	403	484	351	4.6	336	0	0.0	18	64	0.7	0.26	0.90
5 FLOCCULATION	50.0	0	0	701	6.3	474	0	0.0	32	32	0.2	0.06	0.22
6 CIRCULAR CLARIFIER	1.0	228	274	10	0.5	274	0	0.0	3	29	7.9	2.90	10.15
6 CIRCULAR CLARIFIER	5.0	479	575	11	1.2	527	0	0.0	7	61	3.3	1.22	4.27
6 CIRCULAR CLARIFIER	10.0	782	938	14	2.0	802	0	0.0	10	99	2.7	0.99	3.47
6 CIRCULAR CLARIFIER	25.0	1549	1859	29	4.7	1851	0	0.0	24	199	2.2	0.80	2.79
6 CIRCULAR CLARIFIER	50.0	2715	3258	39	8.2	2844	0	0.0	38	346	1.9	0.69	2.42
7 CHLORINE FEED SYSTEMS	1.0	15	18	4	1.8	410	0	15.3	9	11	3.0	1.10	3.85
7 CHLORINE FEED SYSTEMS	5.0	35	42	11	2.4	749	0	76.3	27	31	1.7	0.62	2.17
7 CHLORINE FEED SYSTEMS	10.0	57	68	18	3.1	1129	0	152.4	48	54	1.5	0.54	1.89
7 CHLORINE FEED SYSTEMS	25.0	106	127	33	4.6	2020	0	381.1	110	122	1.3	0.49	1.71
7 CHLORINE FEED SYSTEMS	50.0	148	178	43	5.4	2907	0	761.9	203	220	1.2	0.44	1.54

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS* THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
8 CHEMICAL SLUDGE PUMPING-DILUTE	1.0	24	29	0	1.4	45	0	0.0	2	5	1.4	0.50	1.75
8 CHEMICAL SLUDGE PUMPING-DILUTE	5.0	49	59	2	2.8	98	0	0.0	4	10	0.5	0.20	0.70
8 CHEMICAL SLUDGE PUMPING-DILUTE	10.0	50	60	4	3.7	136	0	0.0	5	11	0.3	0.11	0.39
8 CHEMICAL SLUDGE PUMPING-DILUTE	25.0	63	76	9	3.7	154	0	0.0	5	12	0.1	0.05	0.17
8 CHEMICAL SLUDGE PUMPING-DILUTE	50.0	84	101	18	4.5	200	0	0.0	7	17	0.1	0.03	0.12
9 GRAVITY THICKENER	1.0	130	156	3	0.1	298	0	0.0	3	18	4.9	1.80	6.30
9 GRAVITY THICKENER	5.0	130	156	3	0.1	298	0	0.0	3	18	1.0	0.36	1.26
9 GRAVITY THICKENER	10.0	130	156	3	0.1	298	0	0.0	3	18	0.5	0.18	0.63
9 GRAVITY THICKENER	25.0	147	176	3	0.1	305	0	0.0	3	20	0.2	0.08	0.28
9 GRAVITY THICKENER	50.0	174	209	3	0.2	316	0	0.0	3	23	0.1	0.05	0.16
10 CHEMICAL SLUDGE PUMPING-DILUTE	1.0	14	17	0	1.2	35	0	0.0	2	4	1.1	0.40	1.40
10 CHEMICAL SLUDGE PUMPING-DILUTE	5.0	26	31	1	2.0	67	0	0.0	3	6	0.3	0.12	0.42
10 CHEMICAL SLUDGE PUMPING-DILUTE	10.0	37	44	2	2.8	98	0	0.0	4	8	0.2	0.08	0.28
10 CHEMICAL SLUDGE PUMPING-DILUTE	25.0	51	61	4	3.8	142	0	0.0	5	11	0.1	0.04	0.15
10 CHEMICAL SLUDGE PUMPING-DILUTE	50.0	52	62	9	3.7	154	0	0.0	5	11	0.1	0.02	0.08
11 DECANTER CENTRIFUGE	1.0	301	361	38	1.5	729	0	0.0	10	44	12.1	4.40	15.40
11 DECANTER CENTRIFUGE	5.0	313	376	45	1.7	772	0	0.0	11	46	2.5	0.92	3.22
11 DECANTER CENTRIFUGE	10.0	358	430	71	2.6	936	0	0.0	14	55	1.5	0.55	1.93
11 DECANTER CENTRIFUGE	25.0	481	577	146	5.2	1383	0	0.0	23	77	0.8	0.31	1.08
11 DECANTER CENTRIFUGE	50.0	625	750	252	8.3	1906	0	0.0	35	106	0.6	0.21	0.74
12 SLUDGE HAULING	1.0	0	0	0	0.5	64	0	0.0	1	1	0.3	0.10	0.35
12 SLUDGE HAULING	5.0	0	0	0	1.0	214	0	0.0	3	3	0.2	0.06	0.21
12 SLUDGE HAULING	10.0	0	0	0	1.7	404	0	0.0	6	6	0.2	0.06	0.21
12 SLUDGE HAULING	25.0	0	0	0	3.7	988	0	0.0	14	14	0.2	0.06	0.20
12 SLUDGE HAULING	50.0	0	0	0	7.2	2007	0	0.0	27	27	0.1	0.05	0.19

TOTAL COST FOR COMPONENTS 1 THRU 12: CLARIFICATION AND CHLORINATION

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS* THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
CLARIFICATION AND CHLORINATION	1.0	1165	1400	208	8.8	3945	0	77.0	63	180	49.3	18.00	63.00
CLARIFICATION AND CHLORINATION	5.0	2018	2424	606	15.1	4998	0	384.4	129	329	18.0	6.58	23.03
CLARIFICATION AND CHLORINATION	10.0	3017	3624	1125	22.4	6304	0	764.2	209	507	13.9	5.07	17.75
CLARIFICATION AND CHLORINATION	25.0	5464	6556	2648	39.6	10036	0	1912.9	446	985	10.8	3.94	13.79
CLARIFICATION AND CHLORINATION	50.0	8111	9735	5082	60.9	15210	0	3817.4	806	1606	8.8	3.21	11.24

THE FOLLOWING 5 PROCESSES ARE COST COMPONENTS OF RAPID SAND FILTRATION

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS* THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
13 GRAVITY FILTRATION STRUCTURE	1.0	364	437	32	3.8	2158	0	0.0	26	67	18.4	6.70	23.45
13 GRAVITY FILTRATION STRUCTURE	5.0	881	1057	80	10.1	2987	0	0.0	42	142	7.8	2.84	9.94
13 GRAVITY FILTRATION STRUCTURE	10.0	1516	1819	142	18.1	4393	0	0.0	66	238	6.5	2.38	8.33
13 GRAVITY FILTRATION STRUCTURE	25.0	2698	3238	273	34.9	9338	0	0.0	137	443	4.9	1.77	6.20
13 GRAVITY FILTRATION STRUCTURE	50.0	3944	4733	396	54.9	18630	0	0.0	253	700	3.8	1.40	4.90

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	\$TOTAL ANNUAL COST FACTORS\$			
										THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
14 FILTRA-HYDRAULIC SURFACE WASH	1.0	25	30	5	0.0	58	0	0.0	1	4	1.1	0.40	1.40
14 FILTRA-HYDRAULIC SURFACE WASH	5.0	76	91	26	0.0	289	0	0.0	4	13	0.7	0.26	0.91
14 FILTRA-HYDRAULIC SURFACE WASH	10.0	102	122	49	0.0	306	0	0.0	5	17	0.5	0.17	0.59
14 FILTRA-HYDRAULIC SURFACE WASH	25.0	195	234	121	0.1	373	0	0.0	7	29	0.3	0.12	0.41
14 FILTRA-HYDRAULIC SURFACE WASH	50.0	340	408	246	0.1	473	0	0.0	12	51	0.3	0.10	0.36
15 FILTRA-BACKWASH PUMPING SYSTEM	1.0	232	278	8	0.0	6	0	0.0	0	26	7.1	2.60	9.10
15 FILTRA-BACKWASH PUMPING SYSTEM	5.0	696	835	42	0.2	29	0	0.0	2	81	4.4	1.62	5.67
15 FILTRA-BACKWASH PUMPING SYSTEM	10.0	976	1171	83	0.3	34	0	0.0	3	114	3.1	1.14	3.99
15 FILTRA-BACKWASH PUMPING SYSTEM	25.0	1430	1716	206	0.6	52	0	0.0	7	169	1.9	0.68	2.37
15 FILTRA-BACKWASH PUMPING SYSTEM	50.0	2749	3299	415	1.1	71	0	0.0	14	325	1.8	0.65	2.28
16 MEDIA-RAPID SAND FILTRATION	1.0	11	13	0	0.0	0	0	0.0	0	1	0.3	0.10	0.35
16 MEDIA-RAPID SAND FILTRATION	5.0	21	25	0	0.0	0	0	0.0	0	2	0.1	0.04	0.14
16 MEDIA-RAPID SAND FILTRATION	10.0	35	42	0	0.0	0	0	0.0	0	4	0.1	0.04	0.14
16 MEDIA-RAPID SAND FILTRATION	25.0	75	90	0	0.0	0	0	0.0	0	8	0.1	0.03	0.11
16 MEDIA-RAPID SAND FILTRATION	50.0	136	163	0	0.0	0	0	0.0	0	15	0.1	0.03	0.11
17 SUPPLY PUMPING	1.0	30	36	45	0.3	520	0	0.0	7	10	2.7	1.00	3.50
17 SUPPLY PUMPING	5.0	47	56	226	0.9	623	0	0.0	14	19	1.0	0.38	1.33
17 SUPPLY PUMPING	10.0	69	83	451	1.6	747	0	0.0	23	31	0.8	0.31	1.09
17 SUPPLY PUMPING	25.0	132	158	1128	3.7	1096	0	0.0	49	64	0.7	0.26	0.90
17 SUPPLY PUMPING	50.0	234	281	2254	7.6	1618	0	0.0	91	118	0.6	0.24	0.83
TOTAL COST FOR COMPONENTS 13 THRU 17: RAPID SAND FILTRATION													
RAPID SAND FILTRATION	1.0	758	910	90	4.2	2742	0	0.0	34	108	29.6	10.80	37.80
RAPID SAND FILTRATION	5.0	1978	2371	374	11.1	3928	0	0.0	62	257	14.1	5.14	17.99
RAPID SAND FILTRATION	10.0	3101	3720	725	19.9	5480	0	0.0	97	404	11.1	4.04	14.14
RAPID SAND FILTRATION	25.0	5207	6249	1728	39.3	10859	0	0.0	200	713	7.8	2.85	9.98
RAPID SAND FILTRATION	50.0	8512	10214	3311	63.7	20792	0	0.0	370	1209	6.6	2.42	8.46
THE FOLLOWING 7 PROCESSES ARE COST COMPONENTS OF MIXED MEDIA FILTRATION													
18 GRAVITY FILTRATION STRUCTURE	1.0	193	232	16	1.8	1928	0	0.0	22	44	12.1	4.40	15.40
18 GRAVITY FILTRATION STRUCTURE	5.0	501	601	44	5.4	2355	0	0.0	30	87	4.8	1.74	6.09
18 GRAVITY FILTRATION STRUCTURE	10.0	797	956	72	9.0	2836	0	0.0	40	130	3.6	1.30	4.55
18 GRAVITY FILTRATION STRUCTURE	25.0	1565	1878	147	18.7	4524	0	0.0	68	245	2.7	0.98	3.43
18 GRAVITY FILTRATION STRUCTURE	50.0	2420	2904	240	30.6	7740	0	0.0	115	389	2.1	0.78	2.72

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS*			
										THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
19 FILTRA-HYDRAULIC SURFACE WASH	1.0	21	25	2	0.0	54	0	0.0	1	3	0.8	0.30	1.05
19 FILTRA-HYDRAULIC SURFACE WASH	5.0	38	46	10	0.0	115	0	0.0	1	5	0.3	0.10	0.35
19 FILTRA-HYDRAULIC SURFACE WASH	10.0	56	67	20	0.0	178	0	0.0	2	8	0.2	0.08	0.28
19 FILTRA-HYDRAULIC SURFACE WASH	25.0	97	116	49	0.0	248	0	0.0	4	15	0.2	0.06	0.21
19 FILTRA-HYDRAULIC SURFACE WASH	50.0	162	194	97	0.1	311	0	0.0	6	24	0.1	0.05	0.17
20 FILTRA-BACKWASH PUMPING SYSTEM	1.0	142	170	3	0.0	5	0	0.0	0	16	4.4	1.60	5.60
20 FILTRA-BACKWASH PUMPING SYSTEM	5.0	348	418	17	0.1	12	0	0.0	1	40	2.2	0.80	2.80
20 FILTRA-BACKWASH PUMPING SYSTEM	10.0	539	647	33	0.1	19	0	0.0	1	62	1.7	0.62	2.17
20 FILTRA-BACKWASH PUMPING SYSTEM	25.0	883	1060	83	0.2	29	0	0.0	3	103	1.1	0.41	1.44
20 FILTRA-BACKWASH PUMPING SYSTEM	50.0	1211	1453	166	0.4	43	0	0.0	6	143	0.8	0.29	1.00
21 MEDIA-MIXED MEDIA FILTRATION	1.0	12	14	0	0.0	0	0	0.0	0	1	0.3	0.10	0.35
21 MEDIA-MIXED MEDIA FILTRATION	5.0	34	41	0	0.0	0	0	0.0	0	4	0.2	0.08	0.28
21 MEDIA-MIXED MEDIA FILTRATION	10.0	56	67	0	0.0	0	0	0.0	0	6	0.2	0.06	0.21
21 MEDIA-MIXED MEDIA FILTRATION	25.0	119	143	0	0.0	0	0	0.0	0	13	0.1	0.05	0.18
21 MEDIA-MIXED MEDIA FILTRATION	50.0	208	250	0	0.0	0	0	0.0	0	24	0.1	0.05	0.17
22 SUPPLY PUMPING	1.0	30	36	45	0.3	520	0	0.0	7	10	2.7	1.00	3.50
22 SUPPLY PUMPING	5.0	47	56	226	0.9	623	0	0.0	14	19	1.0	0.38	1.33
22 SUPPLY PUMPING	10.0	69	83	451	1.6	747	0	0.0	23	31	0.8	0.31	1.09
22 SUPPLY PUMPING	25.0	132	158	1128	3.7	1096	0	0.0	49	64	0.7	0.26	0.90
22 SUPPLY PUMPING	50.0	234	281	2254	7.6	1618	0	0.0	91	118	0.6	0.24	0.83
23 POLYMER FEED SYSTEMS	1.0	44	53	23	0.2	198	0	0.3	4	9	2.5	0.90	3.15
23 POLYMER FEED SYSTEMS	5.0	46	55	23	0.2	198	0	1.5	9	14	0.8	0.28	0.98
23 POLYMER FEED SYSTEMS	10.0	51	61	23	0.3	199	0	3.0	15	21	0.6	0.21	0.74
23 POLYMER FEED SYSTEMS	25.0	67	80	23	0.3	201	0	7.6	33	41	0.4	0.16	0.57
23 POLYMER FEED SYSTEMS	50.0	100	120	46	0.6	403	0	11.4	52	63	0.3	0.13	0.44
24 ALUM FEED SYSTEM	1.0	24	29	9	0.2	284	0	15.3	4	7	1.9	0.70	2.45
24 ALUM FEED SYSTEM	5.0	41	49	10	0.2	293	0	76.2	9	14	0.8	0.28	0.98
24 ALUM FEED SYSTEM	10.0	60	72	11	0.2	304	0	152.4	15	22	0.6	0.22	0.77
24 ALUM FEED SYSTEM	25.0	106	127	15	0.2	341	0	381.1	33	45	0.5	0.18	0.63
24 ALUM FEED SYSTEM	50.0	149	179	21	0.2	405	0	762.1	62	79	0.4	0.16	0.55
TOTAL COST FOR COMPONENTS 18 THRU 24: MIXED MEDIA FILTRATION													
MIXED MEDIA FILTRATION	1.0	532	639	98	2.6	2989	0	15.6	38	90	24.7	9.00	31.50
MIXED MEDIA FILTRATION	5.0	1211	1453	330	6.8	3596	0	77.7	64	183	10.0	3.66	12.81
MIXED MEDIA FILTRATION	10.0	1869	2244	610	11.2	4283	0	155.5	96	280	7.7	2.80	9.80
MIXED MEDIA FILTRATION	25.0	3410	4094	1445	23.2	6439	0	388.7	190	526	5.8	2.10	7.36
MIXED MEDIA FILTRATION	50.0	5155	6185	2824	39.6	10520	0	773.5	332	840	4.6	1.68	5.88

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS**			
										THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
THE FOLLOWING 3 PROCESSES ARE COST COMPONENTS OF ACTIVATED CARBON ADSORPTION													
25 GRANULAR ACT CARBON CONTACTORS	1.0	236	283	35	1.8	1893	0	0.0	22	49	13.4	4.90	17.15
25 GRANULAR ACT CARBON CONTACTORS	5.0	595	714	64	5.7	2304	0	0.0	31	98	5.4	1.96	6.86
25 GRANULAR ACT CARBON CONTACTORS	10.0	1026	1231	100	10.4	2870	0	0.0	42	158	4.3	1.58	5.53
25 GRANULAR ACT CARBON CONTACTORS	25.0	2012	2414	187	21.8	4593	0	0.0	73	301	3.3	1.20	4.21
25 GRANULAR ACT CARBON CONTACTORS	50.0	3103	3724	298	36.2	7947	0	0.0	125	477	2.6	0.95	3.34
26 GRANULAR ACTIVATED CARBON	1.0	19	23	0	0.0	0	0	0.0	0	2	0.5	0.20	0.70
26 GRANULAR ACTIVATED CARBON	5.0	76	91	0	0.0	0	0	0.0	0	9	0.5	0.18	0.63
26 GRANULAR ACTIVATED CARBON	10.0	151	181	0	0.0	0	0	0.0	0	17	0.5	0.17	0.59
26 GRANULAR ACTIVATED CARBON	25.0	359	431	0	0.0	0	0	0.0	0	41	0.4	0.16	0.57
26 GRANULAR ACTIVATED CARBON	50.0	712	854	0	0.0	0	0	0.0	0	81	0.4	0.16	0.57
27 GRAN ACT CARBON REGENERATION	1.0	581	697	161	1.2	188	458	1.2	11	77	21.1	7.70	26.95
27 GRAN ACT CARBON REGENERATION	5.0	581	697	191	2.1	509	1978	6.1	27	93	5.1	1.86	6.51
27 GRAN ACT CARBON REGENERATION	10.0	701	841	222	3.0	890	3791	12.1	46	125	3.4	1.25	4.38
27 GRAN ACT CARBON REGENERATION	25.0	1026	1231	273	4.4	1798	8145	30.5	95	211	2.3	0.84	2.95
27 GRAN ACT CARBON REGENERATION	50.0	1473	1768	321	5.9	3327	14914	60.9	173	340	1.9	0.68	2.38
TOTAL COST FOR COMPONENTS 25 THRU 27: ACTIVATED CARBON ADSORPTION													
ACTIVATED CARBON ADSORPTION	1.0	960	1152	196	3.0	2081	458	1.2	33	128	35.1	12.80	44.80
ACTIVATED CARBON ADSORPTION	5.0	1439	1726	255	7.8	2813	1978	6.1	58	200	11.0	4.00	14.00
ACTIVATED CARBON ADSORPTION	10.0	2158	2590	322	13.5	3760	3791	12.1	88	300	8.2	3.00	10.50
ACTIVATED CARBON ADSORPTION	25.0	3904	4686	460	26.2	6391	8145	30.5	168	553	6.1	2.21	7.74
ACTIVATED CARBON ADSORPTION	50.0	6079	7297	619	42.0	11274	14914	60.9	298	898	4.9	1.80	6.29
28 CONCRETE STORAGE, 1 DAY	1.0	491	589	0	0.0	0	0	0.0	0	56	15.3	5.60	19.60
28 CONCRETE STORAGE, 1 DAY	5.0	1466	1759	0	0.0	0	0	0.0	0	166	9.1	3.32	11.62
28 CONCRETE STORAGE, 1 DAY	10.0	2633	3160	0	0.0	0	0	0.0	0	298	8.2	2.98	10.43
28 CONCRETE STORAGE, 1 DAY	25.0	5813	6976	0	0.0	0	0	0.0	0	658	7.2	2.63	9.21
28 CONCRETE STORAGE, 1 DAY	50.0	10206	12247	0	0.0	0	0	0.0	0	1156	6.3	2.31	8.09
29 CONCRETE STORAGE, 2 DAYS	1.0	739	887	0	0.0	0	0	0.0	0	84	23.0	8.40	29.40
29 CONCRETE STORAGE, 2 DAYS	5.0	2633	3160	0	0.0	0	0	0.0	0	298	16.3	5.96	20.86
29 CONCRETE STORAGE, 2 DAYS	10.0	4804	5765	0	0.0	0	0	0.0	0	544	14.9	5.44	19.04
29 CONCRETE STORAGE, 2 DAYS	25.0	10206	12247	0	0.0	0	0	0.0	0	1156	12.7	4.62	16.18
29 CONCRETE STORAGE, 2 DAYS	50.0	16786	20143	0	0.0	0	0	0.0	0	1901	10.4	3.80	13.31

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS* THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
30 CONCRETE STORAGE, 3 DAYS	1.0	984	1181	0	0.0	0	0	0.0	0	111	30.4	11.10	38.85
30 CONCRETE STORAGE, 3 DAYS	5.0	3745	4494	0	0.0	0	0	0.0	0	424	23.2	8.48	29.68
30 CONCRETE STORAGE, 3 DAYS	10.0	6776	8131	0	0.0	0	0	0.0	0	768	21.0	7.68	26.88
30 CONCRETE STORAGE, 3 DAYS	25.0	13752	16502	0	0.0	0	0	0.0	0	1558	17.1	6.23	21.81
30 CONCRETE STORAGE, 3 DAYS	50.0	22646	27175	0	0.0	0	0	0.0	0	2565	14.1	5.13	17.95
31 CONCRETE STORAGE, 4 DAYS	1.0	1226	1471	0	0.0	0	0	0.0	0	139	38.1	13.90	48.65
31 CONCRETE STORAGE, 4 DAYS	5.0	4804	5765	0	0.0	0	0	0.0	0	544	29.8	10.88	38.08
31 CONCRETE STORAGE, 4 DAYS	10.0	8569	10283	0	0.0	0	0	0.0	0	971	26.6	9.71	33.99
31 CONCRETE STORAGE, 4 DAYS	25.0	16786	20143	0	0.0	0	0	0.0	0	1901	20.8	7.60	26.61
31 CONCRETE STORAGE, 4 DAYS	50.0	30454	36545	0	0.0	0	0	0.0	0	3450	18.9	6.90	24.15
***** TREATMENT SYSTEM COST SUMMARIES INCLUDING YARD PIPING AT 15 PERCENT OF CONSTRUCTION COST *****													
CONVENTIONAL WATER TREATMENT	1.0	1923	2310	298	12.9	6687	0	77.0	97	288	78.9	28.80	100.80
CONVENTIONAL WATER TREATMENT	5.0	3996	4795	980	26.2	8926	0	384.4	191	586	32.1	11.72	41.02
CONVENTIONAL WATER TREATMENT	10.0	6118	7344	1850	42.3	11784	0	764.2	306	911	25.0	9.11	31.89
CONVENTIONAL WATER TREATMENT	25.0	10671	12805	4376	79.0	20895	0	1912.9	646	1698	18.6	6.79	23.77
CONVENTIONAL WATER TREATMENT	50.0	16623	19949	8393	124.6	36002	0	3817.4	1176	2815	15.4	5.63	19.71
CONVEN WTR TRT + STORAGE,1 DAY	1.0	2487	2987	298	12.9	6687	0	77.0	97	344	94.2	34.40	120.40
CONVEN WTR TRT + STORAGE,1 DAY	5.0	5681	6817	980	26.2	8926	0	384.4	191	752	41.2	15.04	52.64
CONVEN WTR TRT + STORAGE,1 DAY	10.0	9145	10978	1850	42.3	11784	0	764.2	306	1209	33.1	12.09	42.32
CONVEN WTR TRT + STORAGE,1 DAY	25.0	17355	20827	4376	79.0	20895	0	1912.9	646	2356	25.8	9.42	32.98
CONVEN WTR TRT + STORAGE,1 DAY	50.0	28359	34033	8393	124.6	36002	0	3817.4	1176	3971	21.8	7.94	27.80
CONVEN WTR TRT + STORAGE,2 DAY	1.0	2772	3330	298	12.9	6687	0	77.0	97	372	101.9	37.20	130.20
CONVEN WTR TRT + STORAGE,2 DAY	5.0	7023	8429	980	26.2	8926	0	384.4	191	884	48.4	17.68	61.88
CONVEN WTR TRT + STORAGE,2 DAY	10.0	11642	13973	1850	42.3	11784	0	764.2	306	1455	39.9	14.55	50.93
CONVEN WTR TRT + STORAGE,2 DAY	25.0	22407	26889	4376	79.0	20895	0	1912.9	646	2854	31.3	11.42	39.96
CONVEN WTR TRT + STORAGE,2 DAY	50.0	35926	43113	8393	124.6	36002	0	3817.4	1176	4716	25.8	9.43	33.01
CONVEN WTR TRT + STORAGE,3 DAY	1.0	3054	3668	298	12.9	6687	0	77.0	97	399	109.3	39.90	139.65
CONVEN WTR TRT + STORAGE,3 DAY	5.0	8302	9963	980	26.2	8926	0	384.4	191	1010	55.3	20.20	70.70
CONVEN WTR TRT + STORAGE,3 DAY	10.0	13910	16694	1850	42.3	11784	0	764.2	306	1679	46.0	16.79	58.77
CONVEN WTR TRT + STORAGE,3 DAY	25.0	26485	31782	4376	79.0	20895	0	1912.9	646	3256	35.7	13.02	45.58
CONVEN WTR TRT + STORAGE,3 DAY	50.0	42665	51200	8393	124.6	36002	0	3817.4	1176	5380	29.5	10.76	37.66
CONVEN WTR TRT + STORAGE,4 DAY	1.0	3332	4001	298	12.9	6687	0	77.0	97	427	117.0	42.70	149.45
CONVEN WTR TRT + STORAGE,4 DAY	5.0	9520	11424	980	26.2	8926	0	384.4	191	1130	61.9	22.60	79.10
CONVEN WTR TRT + STORAGE,4 DAY	10.0	15972	19169	1850	42.3	11784	0	764.2	306	1882	51.6	18.82	65.87
CONVEN WTR TRT + STORAGE,4 DAY	25.0	29974	35969	4376	79.0	20895	0	1912.9	646	3599	39.4	14.40	50.39
CONVEN WTR TRT + STORAGE,4 DAY	50.0	51645	61975	8393	124.6	36002	0	3817.4	1176	6265	34.3	12.53	43.86

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS*			
										THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
UPGRADED WATER TREATMENT	1.0	2657	3191	502	14.3	9015	458	93.8	134	398	109.0	39.80	139.30
UPGRADED WATER TREATMENT	5.0	4668	5603	1191	29.6	11407	1978	468.2	251	712	39.0	14.24	49.84
UPGRADED WATER TREATMENT	10.0	7044	8458	2057	47.0	14347	3791	931.8	393	1087	29.8	10.87	38.05
UPGRADED WATER TREATMENT	25.0	12778	15336	4553	89.1	22866	8145	2332.0	804	2064	22.6	8.26	28.90
UPGRADED WATER TREATMENT	50.0	19345	23217	8525	142.5	37004	14914	4651.8	1436	3344	18.3	6.69	23.41
UPGRD WTR TRT + STORAGE,1 DAY	1.0	3221	3868	502	14.3	9015	458	93.8	134	454	124.4	45.40	158.90
UPGRD WTR TRT + STORAGE,1 DAY	5.0	6353	7625	1191	29.6	11407	1978	468.2	251	878	48.1	17.56	61.46
UPGRD WTR TRT + STORAGE,1 DAY	10.0	10071	12092	2057	47.0	14347	3791	931.8	393	1385	37.9	13.85	48.48
UPGRD WTR TRT + STORAGE,1 DAY	25.0	19462	23358	4553	89.1	22866	8145	2332.0	804	2722	29.8	10.89	38.11
UPGRD WTR TRT + STORAGE,1 DAY	50.0	31081	37301	8525	142.5	37004	14914	4651.8	1436	4500	24.7	9.00	31.50
UPGRD WTR TRT + STORAGE,2 DAY	1.0	3506	4211	502	14.3	9015	458	93.8	134	482	132.1	48.20	168.70
UPGRD WTR TRT + STORAGE,2 DAY	5.0	7695	9237	1191	29.6	11407	1978	468.2	251	1010	55.3	20.20	70.70
UPGRD WTR TRT + STORAGE,2 DAY	10.0	12568	15087	2057	47.0	14347	3791	931.8	393	1631	44.7	16.31	57.09
UPGRD WTR TRT + STORAGE,2 DAY	25.0	24514	29420	4553	89.1	22866	8145	2332.0	804	3220	35.3	12.88	45.08
UPGRD WTR TRT + STORAGE,2 DAY	50.0	38648	46381	8525	142.5	37004	14914	4651.8	1436	5245	28.7	10.49	36.72
UPGRD WTR TRT + STORAGE,3 DAY	1.0	3788	4549	502	14.3	9015	458	93.8	134	509	139.5	50.90	178.15
UPGRD WTR TRT + STORAGE,3 DAY	5.0	8974	10771	1191	29.6	11407	1978	468.2	251	1136	62.2	22.72	79.52
UPGRD WTR TRT + STORAGE,3 DAY	10.0	14836	17808	2057	47.0	14347	3791	931.8	393	1855	50.8	18.55	64.93
UPGRD WTR TRT + STORAGE,3 DAY	25.0	28592	34313	4553	89.1	22866	8145	2332.0	804	3622	39.7	14.49	50.71
UPGRD WTR TRT + STORAGE,3 DAY	50.0	45387	54468	8525	142.5	37004	14914	4651.8	1436	5909	32.4	11.82	41.36
UPGRD WTR TRT + STORAGE,4 DAY	1.0	4066	4882	502	14.3	9015	458	93.8	134	537	147.1	53.70	187.95
UPGRD WTR TRT + STORAGE,4 DAY	5.0	10192	12232	1191	29.6	11407	1978	468.2	251	1256	68.8	25.12	87.92
UPGRD WTR TRT + STORAGE,4 DAY	10.0	16898	20283	2057	47.0	14347	3791	931.8	393	2058	56.4	20.58	72.03
UPGRD WTR TRT + STORAGE,4 DAY	25.0	32081	38500	4553	89.1	22866	8145	2332.0	804	3965	43.5	15.86	55.51
UPGRD WTR TRT + STORAGE,4 DAY	50.0	54367	65243	8525	142.5	37004	14914	4651.8	1436	6794	37.2	13.59	47.56

DESIGN CRITERIA AND UNIT PROCESS SIZES

PROCESS OR COMPONENT					
DESIGN FLOW,MGD					
AVERAGE:	1.0	5.0	10.0	25.0	50.0
PEAK:	1.0	5.0	10.0	25.0	50.0
1 RAW WATER PUMPING, FIRM CAPACITY, MGD	1.0	5.0	10.0	25.0	50.0
INCLUDES SCREENING & ONE STANDBY PUMP EQUAL TO LARGEST UNIT					
2 RAPID MIX BASIN,VOLUME,CU FT (INCL STNBY)	93.0	464.0	928.0	2320.0	4640.0
NUMBER OF UNITS	2	2	2	2	2
1 MIN DETENTION TIME AT AVERAGE FLOW					
3 ALUM FEED SYSTEM-DRY ALUM,CAPACITY,LBS/HR (INCL STNBY)	42.0	208.0	416.0	1042.0	2080.0
ALUM COAGULATION, CAPACITY=60 MG/L, AVG=40 MG/L					
4 POLYMER FEED SYSTEMS, FEED CAPACITY/UNIT, LBS/DAY	8.3	42.0	83.0	208.0	208.0
NUMBER OF UNITS	2	2	2	2	3
(INCL STANDBY) CAPACITY=1 MG/L, AVG=0.1 MG/L DOSE					
5 FLOCCULATION,TOTAL BASIN VOLUME,CU FT (INCL STNBY)	5560.0	20850.0	41700.0	104250.0	208000.0
HORIZONTAL PADDLE, G=80, DETENTION TIME=30 MIN AT AVG FLOW					
6 CIRCULAR CLARIFIER,SURFACE AREA/UNIT,SQ FT (INCL STNBY)	526.0	2630.0	5260.0	6580.0	13200.0
NUMBER OF UNITS	3	3	3	5	5
OVERFLOW RATE=950 GAL/DAY/SQ FT					
7 CHLORINE FEED SYSTEMS, FEED CAPACITY, LB/DAY	84.0	418.0	835.0	2088.0	4175.0
CAPACITY=10 MG/L DOSE					
8 CHEMICAL SLUDGE PUMPING, FIRM PUMPING CAPACITY, GPM	12.0	56.0	112.0	278.0	555.0
CAPACITY=40 MG/L AT PEAK FLOW AND 0.5% SOLIDS					
9 GRAVITY THICKENER,SURFACE AREA/UNIT,SQ FT (INCL STNBY)	78.0	78.0	78.0	200.0	400.0
NUMBER OF UNITS	2	2	2	2	2
ALUM SLUDGE,OVERFLOW RATE=1000 GPD/SQ FT WITH 0.5% SOLIDS IN					
10 CHEMICAL SLUDGE PUMPING, FIRM PUMPING CAPACITY, GPM	3.0	14.0	28.0	69.0	139.0
THICKENED ALUM SLUDGE, 1% SOLIDS					
11 DECANTER CENTRUFUGE,CENTRIFUGE CAPACITY,GPM (INCL STNBY)	10.0	13.0	25.0	63.0	125.0
NUMBER OF UNITS	2	2	2	2	2
ALUM SLUDGE AT 1% SOLIDS INFLUENT CONCENTRATION					
12 SLUDGE HAULING, ANNUAL VOLUME, CU YD	361.0	1810.0	3610.0	9030.0	18100.0
ALUM SLUDGE, CONCENTRATED TO 20% SOLIDS					
13 GRAVITY FILTRATION STRUCTURE, TOTAL FILTER AREA, SQ FT	696.0	2090.0	4160.0	10120.0	19840.0
(INCL STNBY UNITS) FILTRATION RATE=2 GPM/SQ FT, WATER TREAT					
14 FILTRA-HYDRAULIC SURFACE WASH, INDIVIDUAL FILTER AREA, SQ FT	174.0	174.0	347.0	723.0	1240.0
NUMBER OF UNITS	4	12	12	14	16
(INCL STNBY UNITS) FILTRATION RATE=2 GPM/SQ FT, WATER TREAT					
15 FILTRA-BACKWASH PUMPING SYSTEM, FIRM PUMPING CAPACITY, GPM	3130.0	3130.0	6250.0	13000.0	22300.0
NUMBER OF UNITS	4	12	12	14	16
(INCL STNBY UNITS) BACKWASH CAPACITY = 18 GPM/SQ FT					

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        DESIGN CRITERIA AND UNIT PROCESS SIZES

PROCESS OR COMPONENT                                 DESIGN FLOW,MGD
                                                        AVERAGE:        1.0       5.0       10.0       25.0       50.0
                                                        PEAK:           1.0       5.0       10.0       25.0       50.0


 16 MEDIA-RAPID SAND FILTRATION, TOTAL FILTER AREA, SQ FT             696.0    2090.0     4160.0    10120.0    19840.0
    (INCL STNBY UNITS) WATER TREAT, FILTRATION RATE=2 GPM/SQ FT

 17 SUPPLY PUMPING, PUMPING RATE, MGD                                   1.0       5.0       10.0       25.0       50.0
    GRAVITY FILTER OR AWT UPFLOW CARBON CONTACTOR SUPPLY

 18 GRAVITY FILTRATION STRUCTURE, TOTAL FILTER AREA, SQ FT            276.0    1044.0     1848.0     4340.0     8328.0
    (INCL STNBY UNITS)  FILTRATION RATE=5 GPM/SQ FT, WATER & AWT

 19 FILTRA-HYDRAULIC SURFACE WASH, INDIVIDUAL FILTER AREA, SQ FT        69.0     174.0      231.0      434.0      694.0
    NUMBER OF UNITS                                                      4         6          8         10         12
    (INCL STNBY UNITS)  FILTRATION RATE=5 GPM/SQ FT, WATER & AWT

 20 FILTRA-BACKWASH PUMPING SYSTEM, FIRM PUMPING CAPACITY, GPM        1240.0    3130.0     4160.0     7810.0    12500.0
    NUMBER OF UNITS                                                      4         6          8         10         12
    (INCL STNBY UNITS) WATER&AWT, BACKWASH CAPACITY=18 GPM/SQ FT

 21 MEDIA-MIXED MEDIA FILTRATION, TOTAL FILTER AREA, SQ FT            276.0    1044.0     1848.0     4340.0     8328.0
    (INCL STNBY UNITS)  WATER & AWT, FILTRATION RATE=5 GPM/SQ FT

 22 SUPPLY PUMPING,PUMPING RATE, MGD                                    1.0       5.0       10.0       25.0       50.0
    GRAVITY FILTER OR AWT UPFLOW.CARBON CONTACTOR SUPPLY

 23 POLYMER FEED SYSTEMS, FEED CAPACITY/UNIT, LBS/DAY                   8.3      42.0       83.0      208.0      208.0
    NUMBER OF UNITS                                                      2         2          2          2          3
    (INCL STNBY)   COAGULANT AID,1 MG/L CAPACITY,0.1 MG/L AVG

 24 ALUM FEED SYSTEM-DRY ALUM,CAPACITY,LBS/HR (INCL STNBY)             14.0      70.0      140.0      348.0      696.0
    MIXED MEDIA FILTER AID, 20 MG/L CAPACITY, 10 MG/L AVG

 25 GRANULAR ACT CARBON CONTACTORS, TOTAL CONTACTOR AREA,SQ FT        210.0     875.0     1750.0     4200.0     8400.0
    (INCL STNBY)      CONTACT TIME 7.5 MIN, RATE 5 GPM/SQ FT

 26 GRANULAR ACTIVATED CARBON, TOTAL WEIGHT OF CARBON, LBS          31500.0  131250.0   262500.0   630000.0  1260000.0
    CONTACT TIME=7.5 MIN, CARBON WEIGHT=30 LB/ CU FT

 27 GRANULAR CARBON REGENERATION, HEARTH AREA, SQ FT                   28.0      28.0       56.0      139.0      278.0
    40% DOWNTIME,40 LB/SQ FT/DAY; REMOVAL=0.5 LB COD/LB CARBON

 28 CONCRETE STORAGE RESERVOIR,STORAGE CAPACITY,MGD                     1.0       5.0       10.0       25.0       50.0
    1 DAY STORAGE, INCLUDES COST OF COVER

 29 CONCRETE STORAGE RESERVOIR,STORAGE CAPACITY,MGD                     2.0      10.0       20.0       50.0      100.0
    2 DAYS STORAGE, INCLUDES COST OF COVER

 30 CONCRETE STORAGE RESERVOIR,STORAGE CAPACITY,MGD                     3.0      15.0       30.0       75.0      150.0
    3 DAYS STORAGE, INCLUDES COST OF COVER

 31 CONCRETE STORAGE RESERVOIR,STORAGE CAPACITY,MGD                     4.0      20.0       40.0      100.0      200.0
    4 DAYS STORAGE, INCLUDES COST OF COVER
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COST INFORMATION:

 COSTS PRESENTED AS DOLLARS ARE CURRENT AS OF JANUARY 1977

 CAPITAL COST FACTORS:  INTEREST RATE(%)    =7
                        NUMBER OF YEARS     =20
                        ENGINEERING(%)      =10    (PER CENT OF CONSTRUCTION COST)
                        LEGAL,FISCAL(%)     =3     (PER CENT OF CONSTRUCTION COST)
                        INT DURING CONST(%)=7      (PER CENT OF CONSTRUCTION COST)
                        YARD PIPING FACTOR =15     (PER CENT OF CONSTRUCTION COST)

 PER CAPITA COSTS:      GAL/PERSON/DAY      =100
                        PEOPLE/HOME         =3.5

 UNIT COST FACTORS:     ELECTRICITY,$/KWH   =0.03
                        LABOR,$/HR          =10
                        FUEL,$/MIL BTU      =3

 CHEMICAL COSTS:        LIME,$/TON          =52
                        ALUM,$/TON          =75
                        CHLORINE,$/TON      =220
                        POLYMER,$/LB        =2

 CONSTN COST INDEXES:   EXCAVATION          =220.6   (ENR SKILLED LABOR)
                        MANUFACTURED EQUIP =195.7    (BLS #114)
                        CONCRETE            =193.1   (BLS #132)
                        STEEL               =221.3   (BLS #101.3)
                        LABOR               =220.6   (ENR SKILLED LABOR)
                        PIPES & VALVES      =209.4   (BLS #114.901)
                        HOUSING             =30      (ACTUAL BLDG COST,$/SQ FT)
                        WHOLESALE PRICE     =188.0   (BLS ALL COMMODITIES)

 EPA CONSTN INDEXES:    SCCT(5 MGD PLANT)  =121      (NATIONAL INDEX VALUE)
                        LCAT(50 MGD PLANT) =132      (NATIONAL INDEX VALUE)
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  . COMPONENT                 AVE  CONSTN  CAPITAL    ELEC   MAINT             FUEL               TOTAL  *TOTAL ANNUAL COST FACTORS*
       OR                    FLOW    COST     COST    THOU   MAT'L   LABOR      MIL      CHEM    O&M/YR   THOU   CTS/   $ PER   $ PER
     SYSTEM                   MGD  THOU $   THOU $  KWH/YR   K$/YR   HR/YR   BTU/YR     TN/YR    THOU $   $     K GAL  CAPITA    HOME

                THE FOLLOWING 12 PROCESSES ARE COST COMPONENTS OF CLARIFICATION AND CHLORINATION

1 RAW WATER PUMPING           1.0     165      198      82     0.6    1017        0       0.0        13     32    8.8    3.20   11.20
1 RAW WATER PUMPING           5.0     491      589     331     1.7    1112        0       0.0        23     79    4.3    1.58    5.53
1 RAW WATER PUMPING          10.0     874     1049     637     3.3    1255        0       0.0        35    134    3.7    1.34    4.69
1 RAW WATER PUMPING          25.0    1798     2158    1435     8.3    1751        0       0.0        69    273    3.0    1.09    3.82
1 RAW WATER PUMPING          50.0    3189     3827    2717    13.5    2839        0       0.0       123    484    2.7    0.97    3.39

2 RAPID MIX                   1.0      11       13      39     0.3     470        0       0.0         6      7    1.9    0.70    2.45
2 RAPID MIX                   5.0      26       31     197     0.6     468        0       0.0        11     14    0.8    0.28    0.98
2 RAPID MIX                  10.0      44       53     394     1.0     472        0       0.0        18     23    0.6    0.23    0.80
2 RAPID MIX                  25.0      92      110     926     2.0     514        0       0.0        35     45    0.5    0.18    0.63
2 RAPID MIX                  50.0     174      209    1852     3.9     675        0       0.0        66     86    0.5    0.17    0.60

3 ALUM FEED SYSTEM            1.0      28       34      10     0.2     293        0      76.7         9     12    3.3    1.20    4.20
3 ALUM FEED SYSTEM            5.0      58       70      15     0.2     341        0     383.2        33     40    2.2    0.80    2.80
3 ALUM FEED SYSTEM           10.0      89      107      21     0.2     405        0     762.1        62     72    2.0    0.72    2.52
3 ALUM FEED SYSTEM           25.0     142      170      36     0.3     602        0    1791.4       142    158    1.7    0.63    2.21
3 ALUM FEED SYSTEM           50.0     151      181      55     0.3    1016        0    3582.8       281    298    1.6    0.60    2.09

4 POLYMER FEED SYSTEMS        1.0      22       26      23     0.2     198        0       0.2         4      6    1.6    0.60    2.10
4 POLYMER FEED SYSTEMS        5.0      23       28      23     0.2     199        0       1.0         7     10    0.5    0.20    0.70
4 POLYMER FEED SYSTEMS       10.0      27       32      23     0.3     200        0       1.9        11     14    0.4    0.14    0.49
4 POLYMER FEED SYSTEMS       25.0      58       70      46     0.5     400        0       4.6        24     31    0.3    0.12    0.43
4 POLYMER FEED SYSTEMS       50.0      95      114      69     0.8     602        0       8.9        45     56    0.3    0.11    0.39

5 FLOCCULATION                1.0      46       55      12     0.5     108        0       0.0         2      7    1.9    0.70    2.45
5 FLOCCULATION                5.0     131      157      58     1.2     177        0       0.0         5     20    1.1    0.40    1.40
5 FLOCCULATION               10.0     220      264     117     2.1     240        0       0.0         8     33    0.9    0.33    1.16
5 FLOCCULATION               25.0     370      444     275     3.9     324        0       0.0        15     57    0.6    0.23    0.80
5 FLOCCULATION               50.0     406      487     551     5.8     370        0       0.0        26     72    0.4    0.14    0.50

6 CIRCULAR CLARIFIER          1.0     163      196      10     0.5     291        0       0.0         4     23    6.3    2.30    8.05
6 CIRCULAR CLARIFIER          5.0     370      444      12     1.4     600        0       0.0         8     50    2.7    1.00    3.50
6 CIRCULAR CLARIFIER         10.0     619      743      15     2.4     925        0       0.0        12     82    2.2    0.82    2.87
6 CIRCULAR CLARIFIER         25.0    1410     1692      31     5.4    2053        0       0.0        27    187    2.0    0.75    2.62
6 CIRCULAR CLARIFIER         50.0    2477     2972      42     9.2    3119        0       0.0        42    323    1.8    0.65    2.26

7 CHLORINE FEED SYSTEMS       1.0      16       19       4     1.8     432        0      19.2        10     12    3.3    1.20    4.20
7 CHLORINE FEED SYSTEMS       5.0      41       49      13     2.6     849        0      95.4        32     37    2.0    0.74    2.59
7 CHLORINE FEED SYSTEMS      10.0      67       80      21     3.4    1303        0     190.5        59     67    1.8    0.67    2.34
7 CHLORINE FEED SYSTEMS      25.0     116      139      36     4.8    2221        0     448.2       127    140    1.5    0.56    1.96
7 CHLORINE FEED SYSTEMS      50.0     156      187      43     5.5    3122        0     896.4       235    253    1.4    0.51    1.77
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        COMPONENT                 AVE   CONSTN  CAPITAL   ELEC   MAINT             FUEL            TOTAL   $TOTAL ANNUAL COST FACTORS$
           OR                     FLOW   COST    COST     THOU   MAT'L   LABOR     MIL      CHEM   O$M/YR   THOU   CTS/   $ PER    $ PER
         SYSTEM                   MGD   THOU $  THOU $  KWH/YR   K$/YR  HR/YR    BTU/YR    TN/YR   THOU $    $    K GAL  CAPITA    HOME

 8 CHEMICAL SLUDGE PUMPING-DILUTE  1.0      26      31       0     1.5      49        0       0.0        2      5    1.4    0.50    1.75
 8 CHEMICAL SLUDGE PUMPING-DILUTE  5.0      51      61       2     3.2     111        0       0.0        4     10    0.5    0.20    0.70
 8 CHEMICAL SLUDGE PUMPING-DILUTE 10.0      52      62       4     3.8     143        0       0.0        5     11    0.3    0.11    0.39
 8 CHEMICAL SLUDGE PUMPING-DILUTE 25.0      67      80      10     3.8     162        0       0.0        6     14    0.2    0.06    0.20
 8 CHEMICAL SLUDGE PUMPING-DILUTE 50.0      91     109      21     4.7     216        0       0.0        8     18    0.1    0.04    0.13

 9 GRAVITY THICKENER               1.0     130     156       3     0.1     298        0       0.0        3     18    4.9    1.80    6.30
 9 GRAVITY THICKENER               5.0     130     156       3     0.1     298        0       0.0        3     18    1.0    0.36    1.26
 9 GRAVITY THICKENER              10.0     133     160       3     0.1     300        0       0.0        3     18    0.5    0.18    0.63
 9 GRAVITY THICKENER              25.0     152     182       3     0.1     307        0       0.0        3     20    0.2    0.08    0.28
 9 GRAVITY THICKENER              50.0     183     220       3     0.2     319        0       0.0        3     24    0.1    0.05    0.17

10 CHEMICAL SLUDGE PUMPING-DILUTE  1.0      15      18       0     1.3      38        0       0.0        2      4    1.1    0.40    1.40
10 CHEMICAL SLUDGE PUMPING-DILUTE  5.0      29      35       1     2.3      77        0       0.0        3      6    0.3    0.12    0.42
10 CHEMICAL SLUDGE PUMPING-DILUTE 10.0      41      49       2     3.2     111        0       0.0        4      9    0.2    0.09    0.32
10 CHEMICAL SLUDGE PUMPING-DILUTE 25.0      51      61       5     3.7     144        0       0.0        5     11    0.1    0.04    0.15
10 CHEMICAL SLUDGE PUMPING-DILUTE 50.0      54      65      10     3.8     162        0       0.0        6     12    0.1    0.02    0.08

11 DECANTER CENTRIFUGE             1.0     313     376      45     1.7     772        0       0.0       11     46   12.6    4.60   16.10
11 DECANTER CENTRIFUGE             5.0     324     389      51     2.0     814        0       0.0       12     49    2.7    0.98    3.43
11 DECANTER CENTRIFUGE            10.0     380     456      83     3.1    1014        0       0.0       16     59    1.6    0.59    2.07
11 DECANTER CENTRIFUGE            25.0     511     613     166     5.8    1493        0       0.0       26     84    0.9    0.34    1.18
11 DECANTER CENTRIFUGE            50.0     664     797     285     9.2    2041        0       0.0       38    113    0.6    0.23    0.79

12 SLUDGE HAULING                  1.0       0       0       0     0.5      73        0       0.0        1      1    0.3    0.10    0.35
12 SLUDGE HAULING                  5.0       0       0       0     1.2     262        0       0.0        4      4    0.2    0.08    0.28
12 SLUDGE HAULING                 10.0       0       0       0     2.0     500        0       0.0        7      7    0.2    0.07    0.25
12 SLUDGE HAULING                 25.0       0       0       0     4.3    1164        0       0.0       16     16    0.2    0.06    0.22
12 SLUDGE HAULING                 50.0       0       0       0     8.5    2376        0       0.0       32     32    0.2    0.06    0.22

                       TOTAL COST FOR COMPONENTS   1 THRU  12:   CLARIFICATION AND CHLORINATION

CLARIFICATION AND CHLORINATION     1.0    1235    1482     239     9.5    4058        0      96.2       68    191   52.3   19.10   66.85
CLARIFICATION AND CHLORINATION     5.0    2279    2737     736    17.1    5342        0     480.6      150    376   20.6    7.52   26.32
CLARIFICATION AND CHLORINATION    10.0    3492    4191    1378    25.5    6912        0     956.4      250    595   16.3    5.95   20.83
CLARIFICATION AND CHLORINATION    25.0    5273    6327    3092    41.5   10127        0    2246.5      496   1017   11.1    4.07   14.24
CLARIFICATION AND CHLORINATION    50.0    7708    9253    5902    61.6   15601        0    4491.2      907   1665    9.1    3.33   11.66

                     THE FOLLOWING  7 PROCESSES ARE COST COMPONENTS OF MIXED MEDIA FILTRATION

13 GRAVITY FILTRATION STRUCTURE    1.0     222     266      19     2.1    1965        0       0.0       22     47   12.9    4.70   16.45
13 GRAVITY FILTRATION STRUCTURE    5.0     601     721      53     6.6    2509        0       0.0       33    101    5.5    2.02    7.07
13 GRAVITY FILTRATION STRUCTURE   10.0     956    1147      87    11.0    3128        0       0.0       45    153    4.2    1.53    5.36
13 GRAVITY FILTRATION STRUCTURE   25.0    1762    2114     167    21.3    5101        0       0.0       77    277    3.0    1.11    3.88
13 GRAVITY FILTRATION STRUCTURE   50.0    2651    3181     267    34.2    9040        0       0.0      133    433    2.4    0.87    3.03
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COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS* THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
14 FILTRA-HYDRAULIC SURFACE WASH	1.0	22	26	3	0.0	55	0	0.0	1	3	0.8	0.30	1.05
14 FILTRA-HYDRAULIC SURFACE WASH	5.0	41	49	13	0.0	118	0	0.0	2	7	0.4	0.14	0.49
14 FILTRA-HYDRAULIC SURFACE WASH	10.0	62	74	25	0.0	181	0	0.0	3	10	0.3	0.10	0.35
14 FILTRA-HYDRAULIC SURFACE WASH	25.0	108	130	57	0.0	249	0	0.0	4	16	0.2	0.06	0.22
14 FILTRA-HYDRAULIC SURFACE WASH	50.0	184	221	114	0.1	311	0	0.0	7	28	0.2	0.06	0.20
15 FILTRA-BACKWASH PUMPING SYSTEM	1.0	159	191	4	0.0	5	0	0.0	0	18	4.9	1.80	6.30
15 FILTRA-BACKWASH PUMPING SYSTEM	5.0	392	470	21	0.1	12	0	0.0	1	45	2.5	0.90	3.15
15 FILTRA-BACKWASH PUMPING SYSTEM	10.0	601	721	41	0.1	20	0	0.0	2	70	1.9	0.70	2.45
15 FILTRA-BACKWASH PUMPING SYSTEM	25.0	928	1114	98	0.3	31	0	0.0	4	109	1.2	0.44	1.53
15 FILTRA-BACKWASH PUMPING SYSTEM	50.0	1287	1544	195	0.5	45	0	0.0	7	153	0.8	0.31	1.07
16 MEDIA-MIXED MEDIA FILTRATION	1.0	14	17	0	0.0	0	0	0.0	0	2	0.5	0.20	0.70
16 MEDIA-MIXED MEDIA FILTRATION	5.0	41	49	0	0.0	0	0	0.0	0	5	0.3	0.10	0.35
16 MEDIA-MIXED MEDIA FILTRATION	10.0	68	82	0	0.0	0	0	0.0	0	8	0.2	0.08	0.28
16 MEDIA-MIXED MEDIA FILTRATION	25.0	137	164	0	0.0	0	0	0.0	0	15	0.2	0.06	0.21
16 MEDIA-MIXED MEDIA FILTRATION	50.0	237	284	0	0.0	0	0	0.0	0	27	0.1	0.05	0.19
17 SUPPLY PUMPING	1.0	31	37	57	0.4	527	0	0.0	7	10	2.7	1.00	3.50
17 SUPPLY PUMPING	5.0	53	64	282	1.1	654	0	0.0	16	22	1.2	0.44	1.54
17 SUPPLY PUMPING	10.0	80	96	564	1.9	807	0	0.0	27	36	1.0	0.36	1.26
17 SUPPLY PUMPING	25.0	151	181	1326	4.4	1192	0	0.0	56	73	0.8	0.29	1.02
17 SUPPLY PUMPING	50.0	269	323	2650	9.1	1790	0	0.0	106	136	0.7	0.27	0.95
18 POLYMER FEED SYSTEMS	1.0	44	53	23	0.2	198	0	0.4	4	9	2.5	0.90	3.15
18 POLYMER FEED SYSTEMS	5.0	47	56	23	0.2	199	0	1.9	11	16	0.9	0.32	1.12
18 POLYMER FEED SYSTEMS	10.0	54	65	23	0.3	200	0	3.8	18	24	0.7	0.24	0.84
18 POLYMER FEED SYSTEMS	25.0	87	104	46	0.5	400	0	6.8	33	43	0.5	0.17	0.60
18 POLYMER FEED SYSTEMS	50.0	126	151	69	0.8	602	0	11.9	56	70	0.4	0.14	0.49
19 ALUM FEED SYSTEM	1.0	25	30	9	0.2	284	0	19.3	5	8	2.2	0.80	2.80
19 ALUM FEED SYSTEM	5.0	46	55	10	0.2	296	0	95.5	11	16	0.9	0.32	1.12
19 ALUM FEED SYSTEM	10.0	69	83	12	0.2	310	0	191.0	18	26	0.7	0.26	0.91
19 ALUM FEED SYSTEM	25.0	116	139	16	0.2	351	0	446.8	38	51	0.6	0.20	0.71
19 ALUM FEED SYSTEM	50.0	155	186	23	0.2	428	0	893.5	72	90	0.5	0.18	0.63
TOTAL COST FOR COMPONENTS 13 THRU 19: MIXED MEDIA FILTRATION													
MIXED MEDIA FILTRATION	1.0	591	708	115	2.9	3034	0	19.7	39	97	26.6	9.70	33.95
MIXED MEDIA FILTRATION	5.0	1401	1681	402	8.2	3788	0	97.4	74	212	11.6	4.24	14.84
MIXED MEDIA FILTRATION	10.0	2172	2606	752	13.5	4646	0	194.8	113	327	9.0	3.27	11.45
MIXED MEDIA FILTRATION	25.0	3780	4535	1710	26.8	7324	0	453.6	212	584	6.4	2.34	8.18
MIXED MEDIA FILTRATION	50.0	5642	6770	3318	44.9	12216	0	905.4	381	937	5.1	1.87	6.56

COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS* THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
THE FOLLOWING 3 PROCESSES ARE COST COMPONENTS OF ACTIVATED CARBON ADSORPTION													
20 GRANULAR ACT CARBON CONTACTORS	1.0	266	319	38	2.1	1925	0	0.0	23	53	14.5	5.30	18.55
20 GRANULAR ACT CARBON CONTACTORS	5.0	707	848	73	6.9	2443	0	0.0	34	114	6.2	2.28	7.98
20 GRANULAR ACT CARBON CONTACTORS	10.0	1226	1471	117	12.7	3164	0	0.0	48	187	5.1	1.87	6.55
20 GRANULAR ACT CARBON CONTACTORS	25.0	1982	2378	184	21.5	4528	0	0.0	72	296	3.2	1.18	4.14
20 GRANULAR ACT CARBON CONTACTORS	50.0	3071	3685	294	35.7	7808	0	0.0	123	471	2.6	0.94	3.30
21 GRANULAR ACTIVATED CARBON	1.0	24	29	0	0.0	0	0	0.0	0	3	0.8	0.30	1.05
21 GRANULAR ACTIVATED CARBON	5.0	95	114	0	0.0	0	0	0.0	0	11	0.6	0.22	0.77
21 GRANULAR ACTIVATED CARBON	10.0	188	226	0	0.0	0	0	0.0	0	21	0.6	0.21	0.74
21 GRANULAR ACTIVATED CARBON	25.0	422	506	0	0.0	0	0	0.0	0	48	0.5	0.19	0.67
21 GRANULAR ACTIVATED CARBON	50.0	835	1002	0	0.0	0	0	0.0	0	95	0.5	0.19	0.66
22 GRAN ACT CARBON REGENERATION	1.0	581	697	163	1.2	208	553	1.5	12	78	21.4	7.80	27.30
22 GRAN ACT CARBON REGENERATION	5.0	612	734	199	2.3	607	2442	7.6	32	101	5.5	2.02	7.07
22 GRAN ACT CARBON REGENERATION	10.0	759	911	236	3.4	1074	4671	15.2	55	141	3.9	1.41	4.94
22 GRAN ACT CARBON REGENERATION	25.0	1115	1338	282	4.7	2083	9360	35.9	109	235	2.6	0.94	3.29
22 GRAN ACT CARBON REGENERATION	50.0	1604	1925	337	6.3	3821	17252	71.6	199	381	2.1	0.76	2.67
TOTAL COST FOR COMPONENTS 20 THRU 22: ACTIVATED CARBON ADSORPTION													
ACTIVATED CARBON ADSORPTION	1.0	1000	1200	201	3.4	2133	553	1.5	35	134	36.7	13.40	46.90
ACTIVATED CARBON ADSORPTION	5.0	1625	1950	272	9.2	3050	2442	7.6	66	226	12.4	4.52	15.82
ACTIVATED CARBON ADSORPTION	10.0	2497	2997	353	16.1	4238	4671	15.2	103	349	9.6	3.49	12.22
ACTIVATED CARBON ADSORPTION	25.0	4046	4853	466	26.1	6611	9360	35.9	181	579	6.3	2.32	8.11
ACTIVATED CARBON ADSORPTION	50.0	6335	7602	631	42.0	11629	17252	71.6	322	947	5.2	1.89	6.63
23 REVERSE OSMOSIS	1.0	1147	1376	3708	126.2	1982	0	0.0	257	387	106.0	38.70	135.45
23 REVERSE OSMOSIS	5.0	3802	4562	14360	438.1	2370	0	0.0	893	1324	72.5	26.48	92.68
23 REVERSE OSMOSIS	10.0	6975	8370	27371	812.9	2810	0	0.0	1662	2452	67.2	24.52	85.82
23 REVERSE OSMOSIS	25.0	15790	18948	65157	1867.1	3892	0	0.0	3861	5650	61.9	22.60	79.10
23 REVERSE OSMOSIS	50.0	28502	34202	123921	3429.9	5108	0	0.0	7199	10427	57.1	20.85	72.99
24 CONCRETE STORAGE RESERVOIR,1 DAY	1.0	491	589	0	0.0	0	0	0.0	0	56	15.3	5.60	19.60
24 CONCRETE STORAGE RESERVOIR "	5.0	1466	1759	0	0.0	0	0	0.0	0	166	9.1	3.32	11.62
24 CONCRETE STORAGE RESERVOIR "	10.0	2633	3160	0	0.0	0	0	0.0	0	298	8.2	2.98	10.43
24 CONCRETE STORAGE RESERVOIR "	25.0	5813	6976	0	0.0	0	0	0.0	0	658	7.2	2.63	9.21
24 CONCRETE STORAGE RESERVOIR "	50.0	10206	12247	0	0.0	0	0	0.0	0	1156	6.3	2.31	8.09

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       COMPONENT                          AVE    CONSTN  CAPITAL   ELEC   MAINT              FUEL            TOTAL   *TOTAL ANNUAL COST FACTORS*
          OR                              FLOW   COST    COST      THOU   MAT'L    LABOR    MIL      CHEM    O&M/YR   THOU   CTS/   $ PER    $ PER
        SYSTEM                            MGD    THOU $  THOU $   KWH/YR  K$/YR    HR/YR    BTU/YR   TN/YR   THOU $   $      K GAL  CAPITA    HOME

25 CONCRETE STORAGE RESERVOIR,2 DAY  1.0     739     887       0     0.0        0        0      0.0        0      84   23.0    8.40   29.40
25 CONCRETE STORAGE RESERVOIR   .    5.0    2633    3160       0     0.0        0        0      0.0        0     298   16.3    5.96   20.86
25 CONCRETE STORAGE RESERVOIR   .   10.0    4804    5765       0     0.0        0        0      0.0        0     544   14.9    5.44   19.04
25 CONCRETE STORAGE RESERVOIR   .   25.0   10206   12247       0     0.0        0        0      0.0        0    1156   12.7    4.62   16.18
25 CONCRETE STORAGE RESERVOIR   .   50.0   16786   20143       0     0.0        0        0      0.0        0    1901   10.4    3.80   13.31

26 CONCRETE STORAGE RESERVOIR,3 DAY  1.0     984    1181       0     0.0        0        0      0.0        0     311   30.4   11.10   38.85
26 CONCRETE STORAGE RESERVOIR   .    5.0    3745    4494       0     0.0        0        0      0.0        0     424   23.2    8.48   29.68
26 CONCRETE STORAGE RESERVOIR   .   10.0    6776    8131       0     0.0        0        0      0.0        0     768   21.0    7.68   26.88
26 CONCRETE STORAGE RESERVOIR   .   25.0   13752   16502       0     0.0        0        0      0.0        0    1558   17.1    6.23   21.81
26 CONCRETE STORAGE RESERVOIR   .   50.0   22646   27175       0     0.0        0        0      0.0        0    2565   14.1    5.13   17.95

27 CONCRETE STORAGE RESERVOIR,4 DAY  1.0    1226    1471       0     0.0        0        0      0.0        0     139   38.1   13.90   48.65
27 CONCRETE STORAGE RESERVOIR   .    5.0    4804    5765       0     0.0        0        0      0.0        0     544   29.8   10.88   38.08
27 CONCRETE STORAGE RESERVOIR   .   10.0    8569   10283       0     0.0        0        0      0.0        0     971   26.6    9.71   33.99
27 CONCRETE STORAGE RESERVOIR   .   25.0   16786   20143       0     0.0        0        0      0.0        0    1901   20.8    7.60   26.61
27 CONCRETE STORAGE RESERVOIR   .   50.0   30454   36545       0     0.0        0        0      0.0        0    3450   18.9    6.90   24.15


             ***** TREATMENT SYSTEM COST SUMMARIES INCLUDING YARD PIPING AT 15 PERCENT OF CONSTRUCTION COST *****

UPGRADED WATER TRT + R OSMOSIS       1.0    4145    4972    4263   142.0   11207      553    117.4      399     809  221.6   80.90  283.15
UPGRADED WATER TRT + R OSMOSIS       5.0    9677   11614   15770   472.6   14550     2442    585.6     1183    2138  117.2   42.76  149.66
UPGRADED WATER TRT + R OSMOSIS      10.0   16182   19419   29854   868.0   18606     4671   1166.4     2128    3723  102.0   37.23  130.31
UPGRADED WATER TRT + R OSMOSIS      25.0   31257   37505   70425  1961.5   27954     9360   2735.9     4750    7830   85.8   31.32  109.62
UPGRADED WATER TRT + R OSMOSIS      50.0   52462   62957  133772  3578.3   44554    17252   5468.2     8809   13976   76.6   27.95   97.83

UPGD W T + R O + 1 DAY STORAGE       1.0    4709    5649    4263   142.0   11207      553    117.4      399     865  237.0   86.50  302.75
UPGD W T + R O + 1 DAY STORAGE       5.0   11362   13636   15770   472.6   14550     2442    585.6     1183    2304  126.2   46.08  161.28
UPGD W T + R O + 1 DAY STORAGE      10.0   19209   23053   29854   868.0   18606     4671   1166.4     2128    4021  110.2   40.21  140.74
UPGD W T + R O + 1 DAY STORAGE      25.0   37941   45527   70425  1961.5   27954     9360   2735.9     4750    8488   93.0   33.95  118.83
UPGD W T + R O + 1 DAY STORAGE      50.0   64198   77041  133772  3578.3   44554    17252   5468.2     8809   15132   82.9   30.26  105.92

UPGD W T + R O + 2 DAY STORAGE       1.0    4994    5992    4263   142.0   11207      553    117.4      399     893  244.7   89.30  312.55
UPGD W T + R O + 2 DAY STORAGE       5.0   12704   15248   15770   472.6   14550     2442    585.6     1183    2436  133.5   48.72  170.52
UPGD W T + R O + 2 DAY STORAGE      10.0   21706   26048   29854   868.0   18606     4671   1166.4     2128    4267  116.9   42.67  149.35
UPGD W T + R O + 2 DAY STORAGE      25.0   42993   51589   70425  1961.5   27954     9360   2735.9     4750    8986   98.5   35.94  125.80
UPGD W T + R O + 2 DAY STORAGE      50.0   71765   86121  133772  3578.3   44554    17252   5468.2     8809   15877   87.0   31.75  111.14

UPGD W T + R O + 3 DAY STORAGE       1.0    5276    6330    4263   142.0   11207      553    117.4      399     920  252.1   92.00  322.00
UPGD W T + R O + 3 DAY STORAGE       5.0   13983   16782   15770   472.6   14550     2442    585.6     1183    2562  140.4   51.24  179.34
UPGD W T + R O + 3 DAY STORAGE      10.0   23974   28769   29854   868.0   18606     4671   1166.4     2128    4491  123.0   44.91  157.19
UPGD W T + R O + 3 DAY STORAGE      25.0   47071   56482   70425  1961.5   27954     9360   2735.9     4750    9388  102.9   37.55  131.43
UPGD W T + R O + 3 DAY STORAGE      50.0   78504   94208  133772  3578.3   44554    17252   5468.2     8809   16541   90.6   33.08  115.79
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COMPONENT OR SYSTEM	AVE FLOW MGD	CONSTN COST THOU $	CAPITAL COST THOU $	ELEC THOU KWH/YR	MAINT MAT'L K$/YR	LABOR HR/YR	FUEL MIL BTU/YR	CHEM TN/YR	TOTAL O&M/YR THOU $	*TOTAL ANNUAL COST FACTORS* THOU $	CTS/ K GAL	$ PER CAPITA	$ PER HOME
UPGD W T + R O + 4 DAY STORAGE	1.0	5554	6663	4263	142.0	11207	553	117.4	399	948	259.7	94.80	331.80
UPGD W T + R O + 4 DAY STORAGE	5.0	15201	18243	15770	472.6	14550	2442	585.6	1183	2682	147.0	53.64	187.74
UPGD W T + R O + 4 DAY STORAGE	10.0	26036	31244	29854	868.0	18606	4671	1166.4	2128	4694	128.6	46.94	164.29
UPGD W T + R O + 4 DAY STORAGE	25.0	50560	60669	70425	1961.5	27954	9360	2735.9	4750	9731	106.6	38.92	136.23
UPGD W T + R O + 4 DAY STORAGE	50.0	87484	104983	133772	3578.3	44554	17252	5468.2	8809	17426	95.5	34.85	121.98

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               DESIGN CRITERIA AND UNIT PROCESS SIZES

PROCESS OR COMPONENT                          DESIGN FLOW,MGD
                                                   AVERAGE:        1.0        5.0       10.0       25.0       50.0
                                                   PEAK:           1.0        5.0       10.0       25.0       50.0

  1 RAW WATER PUMPING, FIRM CAPACITY, MGD                          1.3        6.3       12.5       29.4       58.8
    INCLUDES SCREENING & ONE STANDBY PUMP EQUAL TO LARGEST UNIT

  2 RAPID MIX BASIN, VOLUME, CU FT                               116.0      580.0     1160.0     2729.0     5459.0
    NUMBER OF UNITS                                                  2          2          2          2          2
    1 MIN DETENTION TIME AT AVERAGE FLOW (INCL STNBY UNIT)

  3 ALUM FEED SYSTEM-DRY ALUM,CAPACITY,LBS/HR (INCL STNBY)        52.6      260.0      520.0     1226.0     2448.0
    ALUM COAGULATION, CAPACITY=60 MG/L, AVG=40 MG/L

  4 POLYMER FEED SYSTEMS, FEED CAPACITY/UNIT, LBS/DAY             10.4       52.5      104.0      125.0      163.0
    NUMBER OF UNITS                                                  2          2          2          3          4
    (INCL STANDBY) CAPACITY=1 MG/L, AVG=0.1 MG/L DOSE

  5 FLOCCULATION,TOTAL BASIN VOLUME,CU FT (INCL STNDBY CAPACITY) 6950.0    26060.0    52125.0   122650.0   245290.0
    HORIZONTAL PADDLE, G=80, DETENTION TIME=30 MIN AT AVG FLOW

  6 CIRCULAR CLARIFIER,SURFACE AREA/UNIT,SQ FT (INCL STNDBY)     658.0     3288.0     6575.0     7741.0    15529.0
    NUMBER OF UNITS                                                  3          3          3          3          3
    OVERFLOW RATE=950 GAL/DAY/SQ FT

  7 CHLORINE FEED SYSTEMS, FEED CAPACITY, LB/DAY                 105.0      523.0     1044.0     2456.0     4912.0
    CAPACITY=10 MG/L DOSE

  8 CHEMICAL SLUDGE PUMPING, FIRM PUMPING CAPACITY, GPM           15.0       70.0      140.0      327.0      654.0
    CAPACITY=40 MG/L AT PEAK FLOW AND 0.5% SOLIDS

  9 GRAVITY THICKENER,SURFACE AREA/UNIT,SQ FT (INCL STNDBY UNIT)  78.0       78.0      100.0      235.0      470.0
    NUMBER OF UNITS                                                  2          2          2          2          2
    ALUM SLUDGE,OVERFLOW RATE=1000 GPD/SQ FT WITH 0.5% SOLIDS IN

 10 CHEMICAL SLUDGE PUMPING,  FIRM PUMPING CAPACITY, GPM            4.0       18.0       35.0       81.0      164.0
    THICKENED ALUM SLUDGE, 1% SOLIDS

 11 DECANTER CENTRUFUGE,CENTRIFUGE CAPACITY,GPM (INCL STNDBY)      13.0       16.0       31.0       74.0      147.0
    NUMBER OF UNITS                                                  2          2          2          2          2
    ALUM SLUDGE AT 1% SOLIDS INFLUENT CONCENTRATION

 12 SLUDGE HAULING, ANNUAL VOLUME, CU YD                         451.0     2263.0     4513.0    10624.0    21294.0
    ALUM SLUDGE, CONCENTRATED TO 20% SOLIDS

 13 GRAVITY FILTRATION STRUCTURE, TOTAL FILTER AREA, SQ FT       344.0     1308.0     2312.0     5110.0     9792.0
    (INCL STNBY UNITS)  FILTRATION RATE=5 GPM/SQ FT, WATER & AWT

 14 FILTRA-HYDRAULIC SURFACE WASH, INDIVIDUAL FILTER AREA, SQ FT  86.0      218.0      289.0      511.0      816.0
    NUMBER OF UNITS                                                  4          6          8         10         12
    (INCL STNBY UNITS)  FILTRATION RATE=5 GPM/SQ FT, WATER & AWT

 15 FILTRA-BACKWASH PUMPING SYSTEM, FIRM PUMPING CAPACITY, GPM  1550.0     3913.0     5200.0     9188.0    14706.0
    NUMBER OF UNITS                                                  4          6          8         10         12
    (INCL STNBY UNITS) WATER&AWT, BACKWASH CAPACITY=18 GPM/SQ FT
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DESIGN CRITERIA AND UNIT PROCESS SIZES

PROCESS OR COMPONENT	DESIGN FLOW,MGD AVERAGE: PEAK:	1.0 1.0	5.0 5.0	10.0 10.0	25.0 25.0	50.0 50.0
16 MEDIA-MIXED MEDIA FILTRATION, TOTAL FILTER AREA, SQ FT (INCL STNBY UNITS) WATER & AWT, FILTRATION RATE=5 GPM/SQ FT		344.0	1308.0	2312.0	5110.0	9792.0
17 SUPPLY PUMPING,PUMPING RATE, MGD GRAVITY FILTER OR AWT UPFLOW CARBON CONTACTOR SUPPLY		1.3	6.3	12.5	29.4	58.8
18 POLYMER FEED SYSTEMS, FEED CAPACITY/UNIT, LBS/DAY		10.4	52.5	104.0	125.0	163.0
NUMBER OF UNITS (INCL STNBY) COAGULANT AID,1 MG/L CAPACITY,0.1 MG/L AVG		2	2	2	3	4
19 ALUM FEED SYSTEM-DRY ALUM,CAPACITY,LBS/HR (INCL STNBY) MIXED MEDIA FILTER AID, 20 MG/L CAPACITY, 10 MG/L AVG		17.6	87.2	174.0	408.0	816.0
20 GRANULAR ACT CARBON CONTACTORS, TOTAL CONTACTOR AREA,SQ FT (INCL STNBY) CONTACT TIME 7.5 MIN, RATE 5 GPM/SQ FT		263.0	1094.0	2170.0	4112.0	8235.0
21 GRANULAR ACTIVATED CARBON, TOTAL WEIGHT OF CARBON, LBS CONTACT TIME=7.5 MIN, CARBON WEIGHT=30 LB/ CU FT		39375.0	164000.0	328125.0	741180.0	1482360.0
22 GRANULAR CARBON REGENERATION, HEARTH AREA, SQ FT 40% DOWNTIME,40 LB/SQ FT/DAY; REMOVAL=0.5 LB COD/LB CARBON		28.0	35.0	70.0	164.0	327.0
23 REVERSE OSMOSIS,PRODUCT WATER FLOW RATE,MGD (INCL STNBY) WATER RECOVERY: 1,5,10 MGD, 80%; 25,50 MGD, 85%		1.5	6.0	11.5	27.5	52.5
24 CONCRETE STORAGE RESERVOIR,STORAGE CAPACITY,MGD 1 DAY STORAGE, INCLUDES COST OF COVER		1.0	5.0	10.0	25.0	50.0
25 CONCRETE STORAGE RESERVOIR,STORAGE CAPACITY,MGD 2 DAYS STORAGE, INCLUDES COST OF COVER		2.0	10.0	20.0	50.0	100.0
26 CONCRETE STORAGE RESERVOIR,STORAGE CAPACITY,MGD 3 DAYS STORAGE, INCLUDES COST OF COVER		3.0	15.0	30.0	75.0	150.0
27 CONCRETE STORAGE RESERVOIR,STORAGE CAPACITY,MGD 4 DAYS STORAGE, INCLUDES COST OF COVER		4.0	20.0	40.0	100.0	200.0

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COST INFORMATION:

 COSTS PRESENTED AS DOLLARS ARE CURRENT AS OF JANUARY 1977

 CAPITAL COST FACTORS:  INTEREST RATE(%)    =7
                        NUMBER OF YEARS     =20
                        ENGINEERING(%)      =10   (PER CENT OF CONSTRUCTION COST)
                        LEGAL,FISCAL(%)     =3    (PER CENT OF CONSTRUCTION COST)
                        INT DURING CONST(%)=7     (PER CENT OF CONSTRUCTION COST)
                        YARD PIPING FACTOR =15    (PER CENT OF CONSTRUCTION COST)

 PER CAPITA COSTS:      GAL/PERSON/DAY      =100
                        PEOPLE/HOME         =3.5

 UNIT COST FACTORS:     ELECTRICITY,$/KWH  =0.03
                        LABOR,$/HR          =10
                        FUEL,$/MIL BTU      =3

 CHEMICAL COSTS:        LIME,$/TON          =52
                        ALUM,$/TON          =75
                        CHLORINE,$/TON      =220
                        POLYMER,$/LB        =2

 CONSTN COST INDEXES:   EXCAVATION          =220.6  (ENR SKILLED LABOR)
                        MANUFACTURED EQUIP =195.7   (BLS #114)
                        CONCRETE            =193.1  (BLS #132)
                        STEEL               =221.3  (BLS #101.3)
                        LABOR               =220.6  (ENR SKILLED LABOR)
                        PIPES & VALVES      =209.4  (BLS #114.901)
                        HOUSING             =30     (ACTUAL BLDG COST,$/SQ FT)
                        WHOLESALE PRICE     =188.0  (BLS ALL COMMODITIES)

 EPA CONSTN INDEXES:    SCCT(5 MGD PLANT)  =121     (NATIONAL INDEX VALUE)
                        LCAT(50 MGD PLANT) =132     (NATIONAL INDEX VALUE)
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